Baldwin & Hiveley

A Recording Device for Indicating
(a) the Flow of Water in Pipes
(b) the Speed of Boats

Civil Engineering

B. S.

1909

A RECORDING DEVICE FOR INDICATING
(*a*) THE FLOW OF WATER IN PIPES
(*b*) THE SPEED OF BOATS

BY

FRANK BOYD BALDWIN
OSCAR GEORGE HIVELEY

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED, JUNE, 1909

UNIVERSITY OF ILLINOIS

June 1, 1909

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

FRANK BOYD BALDWIN and OSCAR GEORGE HIVELY

ENTITLED A RECORDING DEVICE FOR INDICATING
(a) THE FLOW OF WATER IN PIPES
(b) THE SPEED OF BOATS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

F. B. Sanborn
Instructor in Charge

APPROVED: John P. Brooks

HEAD OF DEPARTMENT OF Civil Engineering

INTRODUCTION.

The object of this thesis was to design and perfect a gage that could be used in connection with the Pitot Tube in measuring the velocity of water through pipes. Professor F. B. Sanborn, under whom the thesis has been taken, has already designed and perfected and instrument, called the nozzle piezometer, that measures the velocity of water from nozzles; and it was his suggestion that some device be developed that would enable a form of Pitot Tube to be inserted at any place along a line of pipe and the velocity of flow be directly shown. Although the Pitot Tube has been used successfully to measure the velocity of flow in pipes, it has not been developed in a commercial form. This has been largely to the lack of a suitable recording device. Our problem has been to assist Professor Sanborn in various schemes and in making numeraus tests on trial devices.

A special form of water pitometer for measuring the flow of water in pipes formed the subject of a thesis by H. H. Simmons, but to take readings it was necessary to have water and mercury columns, which could not easily be observed and moved about. Therefore, Professor Sanborn had in mind, in connection with our thesis, the development of some form of gage that would measure directly the difference of pressure of two Pitot openings, one of which opened up stream and one down stream. Such a gage, perfected and correctly calibrated for a given pipe, would show the velocity and quantity of discharge, and put the instrument in a form for commercial use. As is usually the case in experimental work of this nature, it was first necessary to devote a considerable time to planning, designing, testing and calibrating various instruments,

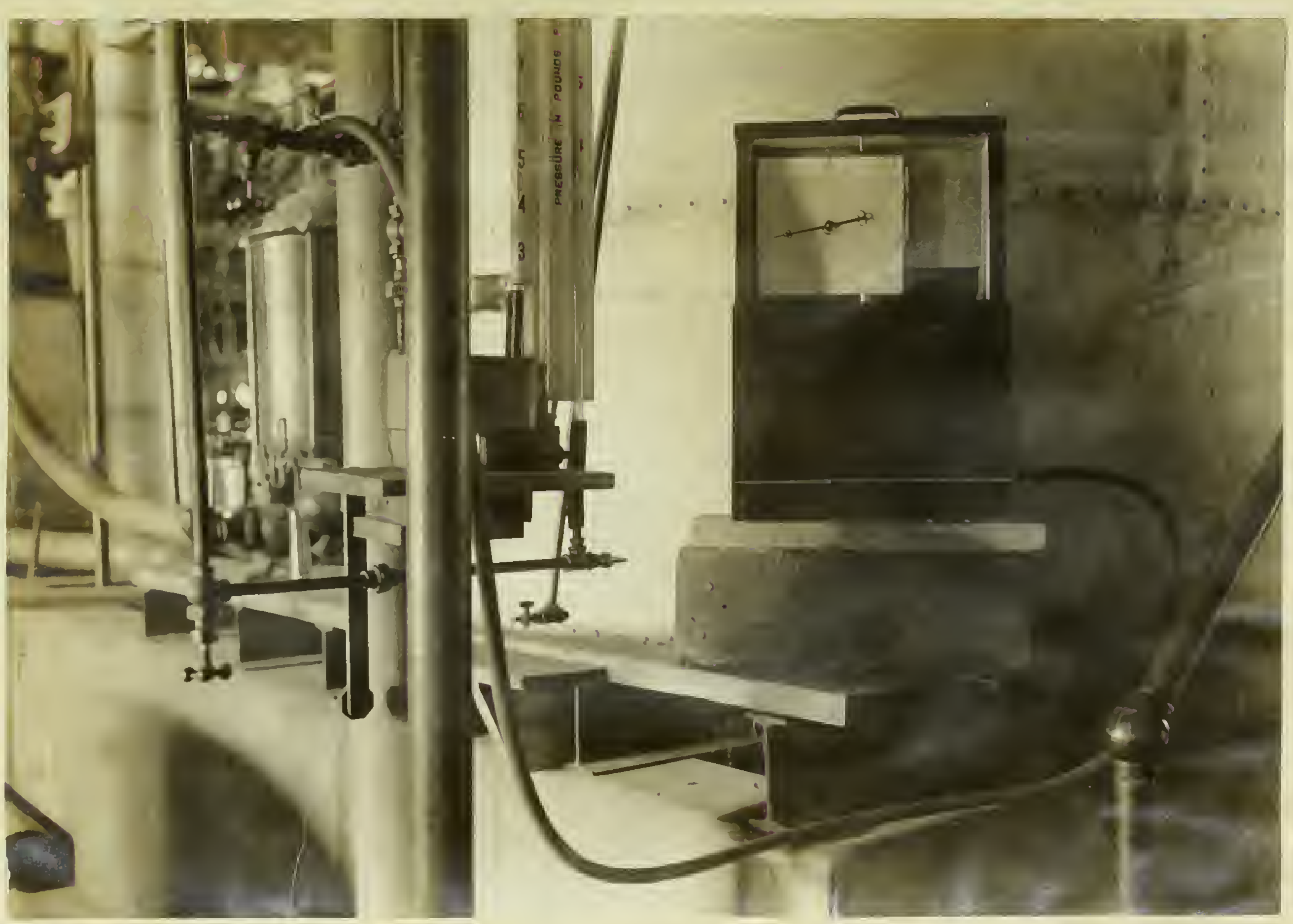
and then to testing some of the materials that were to be used in conjunction with the work.

PRELIMINARY WORK

The work was divided between two of us, one taking up the design and the other the construction of the apparatus. Some of the apparatus, for example, the long glass column gages, to be used in several theses, were designed and constructed principally by Messrs Mc Cool and Stewart. The columns for these scales were 20 feet high and one quarter inch in diameter. A part of our work was to test the glass tubing and to help put it in place. A column of mercury of this height gives a pressure of 120 pounds per square inch. Pressure tests were made with a hand hydraulic pump upon the glass tubing and it was found to stand 165 pounds per square inch. The glass tubing came in sections six and one half feet long and the next problem was to get a reliable connection in order to get the desired length of 20 feet. A piece of ordinary rubber tubing was shellaced on the end of the glass and then wired tightly. The rubber tubing split under a pressure of 75 pounds per square inch. Heavy canvas-lined rubber tubing was next tried and this stood a pressure of 150 pounds per square inch. It was evident that this connection would be suitable, and so, by having the same person do all the wiring in the testing and in the construction of the apparatus, good and efficient joints were secured.

After the mercury-pot and mercury and water columns were fastened to the scales, a pipe system was planned. This pipe system was to connect the pitometer tubes to the mercury and water columns and also to the experimental gage. This latter was put in a convenient place near the columns, as shown in the photograph.

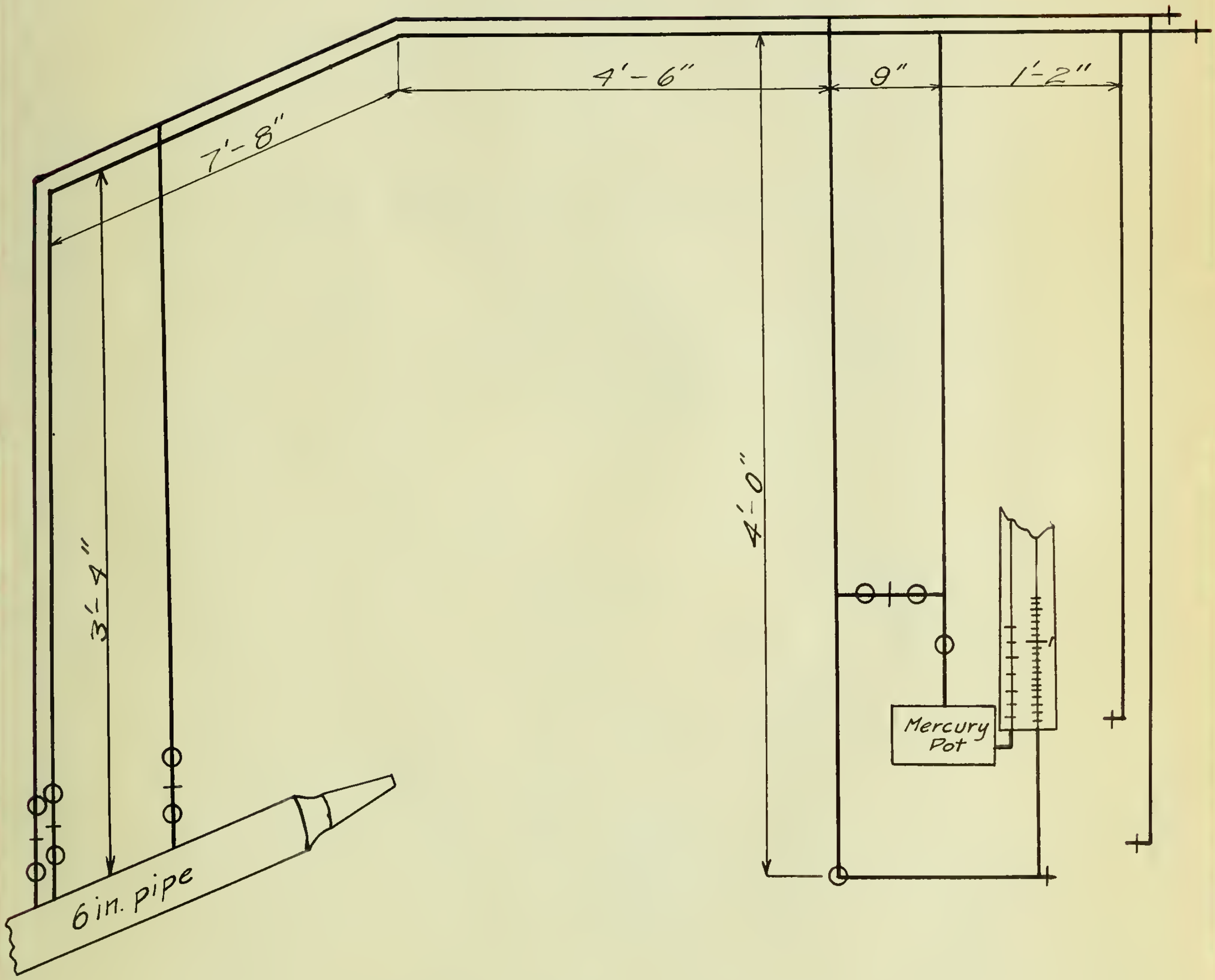
Photograph showing Water and Mercury Columns.



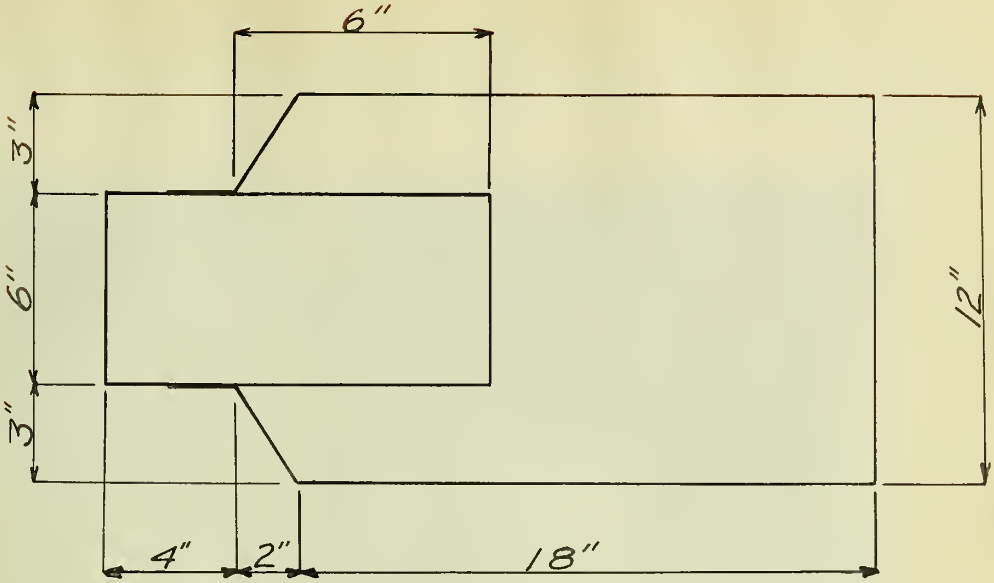
Photograph showing Experimental Gage in position near columns.

As explained below, the piping system had to serve several purposes and it was somewhat complex. The drawing on page 5 shows the details. It was necessary to have some arrangement whereby for low pressures the down stream tube could be connected to the water column and the up stream tube to the mercury column, or vice versa; also for high pressures, to be able to connect one tube to the mercury column and shut the other one off, and vice versa for the second tube; and lastly to connect a piezometer tube in the nozzle ring to either of the columns. Drips were used to allow the removal of air and to detect leakage in the valves. To prevent inaccuracy in the final results, leakage in all valves and connections was carefully guarded against. All iron pipe connections were made water-tight by the use of graphite.

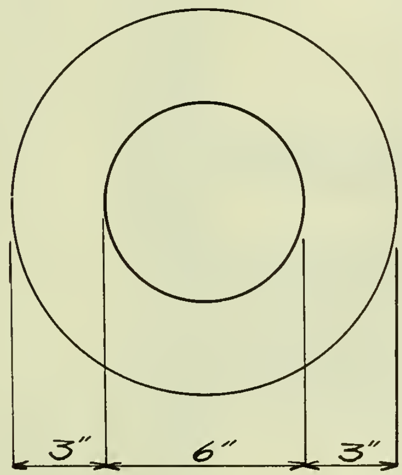
The pitometer tubes were first placed in a 12-inch pipe, which lead into a 6-inch pipe. At the end of this 6-inch pipe was a set of nozzles which discharged into a 12-inch iron elbow set in a block of concrete to hold it stationary. It was found necessary to design a shield to prevent the backflow from the elbow and a general flood in the laboratory. This shield was made of galvanized sheet iron, gage number 18, and a detailed sketch as shown in the figure will explain its use. The entrance to the shield has a 6-inch projection inwards and this scheme for creating a suction through the shield when the nozzle stream was in action, proved very satisfactory. For use with the 4-inch nozzle, the shield had to be fitted with a sliding sleeve which could be pulled out to catch any of the particles of water flying from the stream. The shield itself was made stationary in the end of the 12-inch elbow.



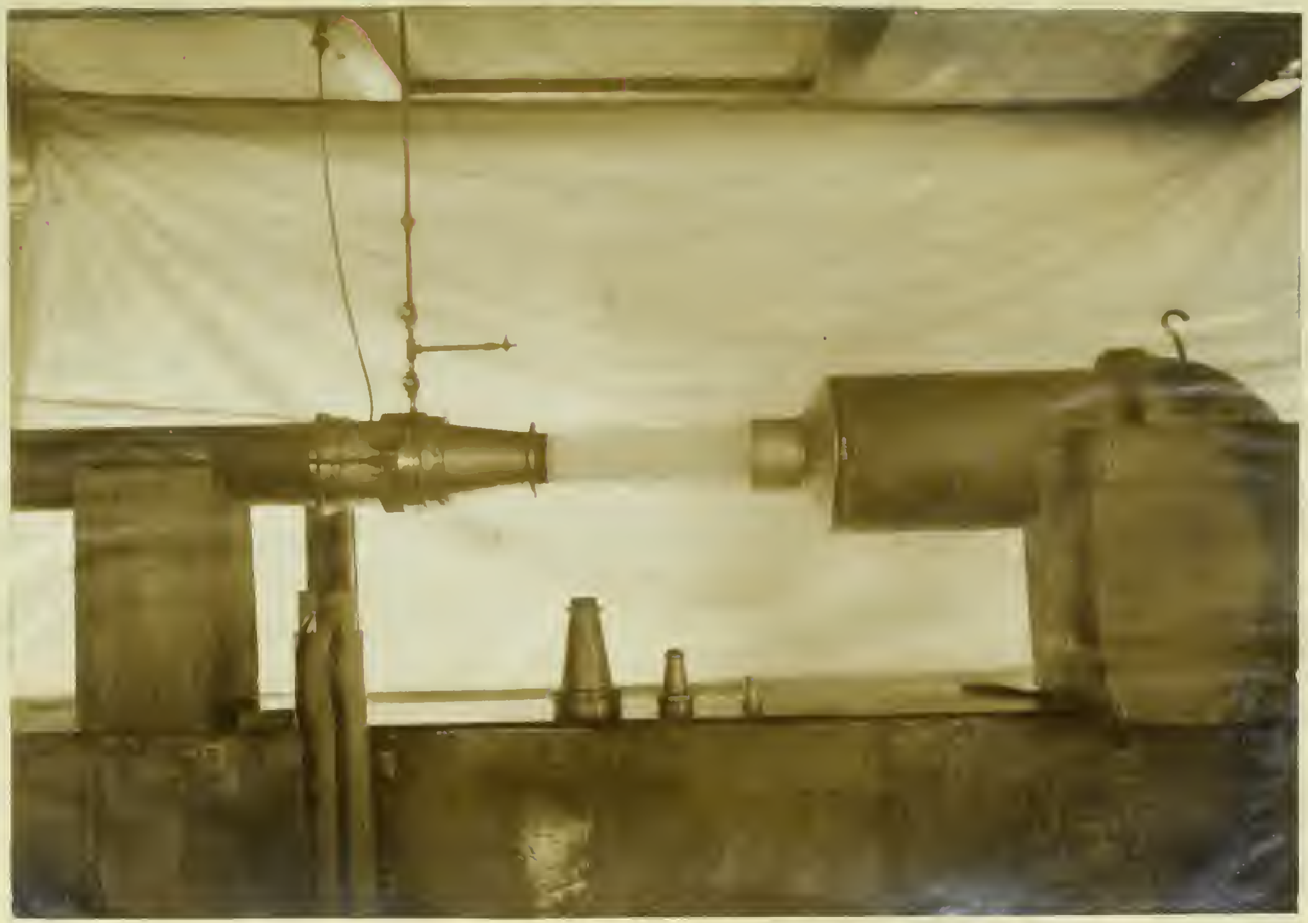
Sketch of Piping System



Longitudinal cross-section of shield used in 12 inch elbow.



End Cross section.



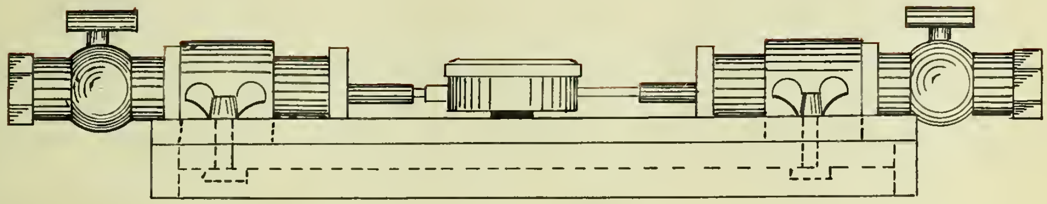
Photograph showing 4-inch nozzle discharging into shield.

EXPERIMENTAL GAGE

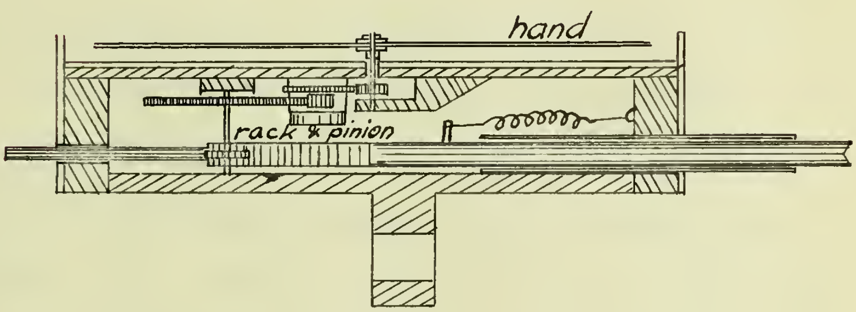
While this apparatus was being constructed the design and construction of the first experimental gage was under way. In the beginning it was thought by Professor Sanborn that differences of pressure might be measured by allowing the pressures of the Pitot Tubes to act upon the pistons of two ordinary steam indicators. A pipe connection was made directly from the pitometer tubes to the pistons of the indicators, and the pistons so placed that the piston rods acted directly against each other. The theory was, that since one of the pressures would be greater than the other, the higher pressure piston would overcome the lowere, and a horizontal pressure would be produced. By means of a simple extensometer this pressure could be measured, and a dial could be calibrated to give the desired readings.

Four indicator pistons were tested under 50 pounds per square inch water pressure. The pistons of the indicator under steam pressure expand somewhat due to the rise of temperature, and when water pressure is applied no expansion results, and there is more leakage. It was thought that a small leakage would not affect the results greatly, especially if the leakage on both pistons was alike, and we concluded that the pistons might be satisfactory in that respect. Of the four pistons that were tested, one was found to be entirely suitable. A second one was selected, but it required a new piston head to make it efficient. These two indicator pistons were next placed in a wooden frame as is shown in the sketch on page 10.

The extensometer that was used with the experimental gage consists of a rack and pinion which rotates a needle simultaneously with the movement of the rack. When the pressure is removed from



Sketch showing arrangement of
Wooden Frame for Indicdtor Pistons and Extensometer



Sketch showing cross-section of
Ames Extensometer

the rack a spring brings the needle back to its initial position on the dial. Before we could use the extensometer to measure the difference of pressure on the pistons of the gage, it was necessary to calibrate the spring. This was done by applying known weights to the end of the rack rod and recording the reading on the dial. Four sets of readings were taken and curves drawn for the same. From these four curves a resultant curve was obtained, as is shown on curve sheet No. I. This resultant curve was used as the calibration curve for the extensometer. The extensometer was then fastened between the two indicators in the wooden frame with the ends of the piston rods butting against the ends of the rack rod.

INITIAL TESTS

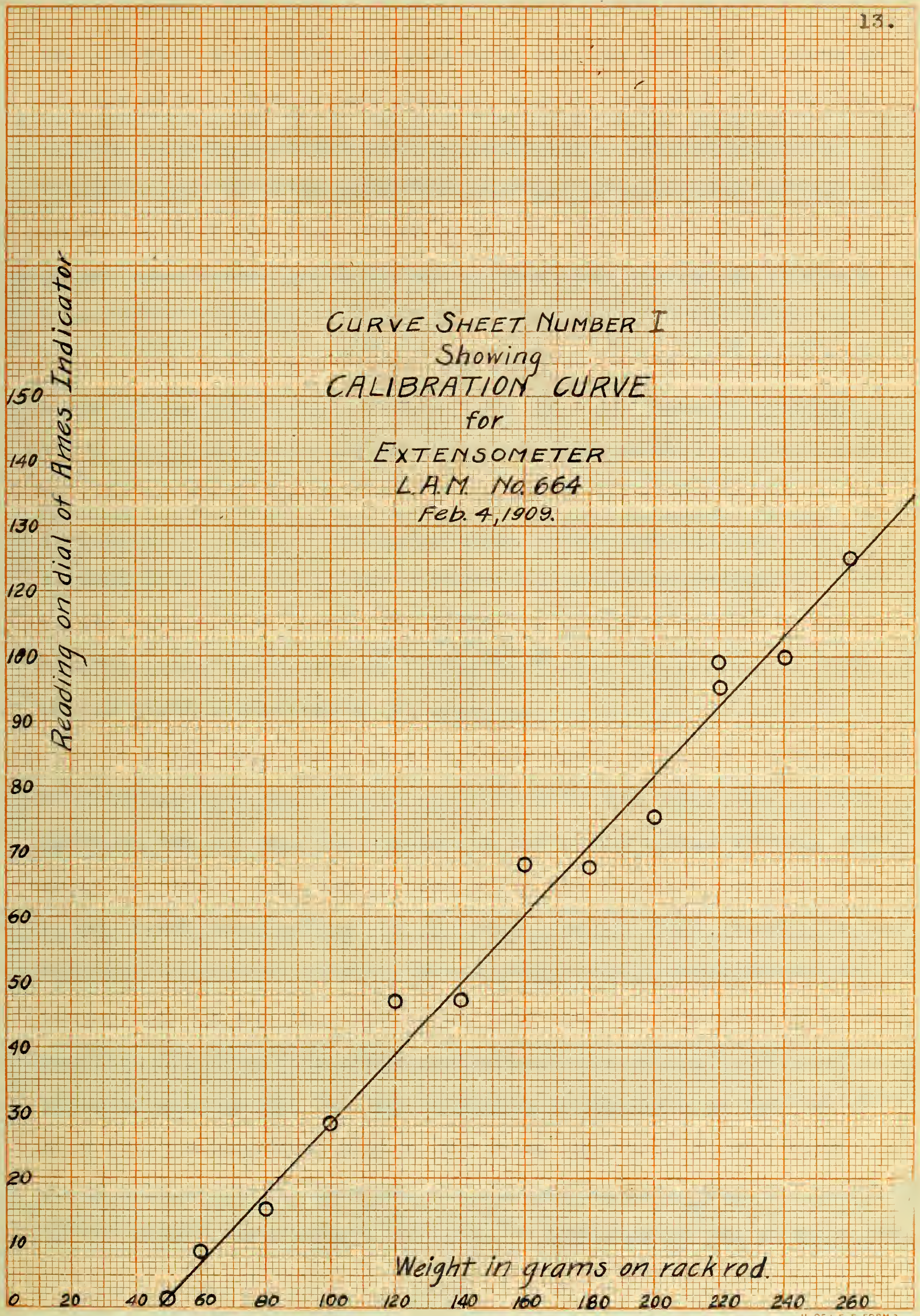
Great care was used in aligning the piston rods so as to get a smooth motion back and forth without any binding. A velocity was set up in the 12-inch pipe, and by opening the valves the pressures were admitted to the cylinders. Care was taken at all times to open the drips and allow the air to get out. The first results were opposite from what were expected, as the down stream side of the apparatus apparently gave the highest pressure. This was evidently due to the friction and binding of the pistons. Owing to the constant presence of water due to the small leakage around the pistons, the wooden frame became warped, thus throwing out the alignment of the piston rods. Considerable time was taken up in the readjustment of the alignment in order to get consecutive readings that would coincide. After many attempts we obtained readings that indicated the higher pressure on the up stream side, and even succeeded in getting some readings that checked.

The next test was carried on with the pressure from the

Data Sheet No. 1.

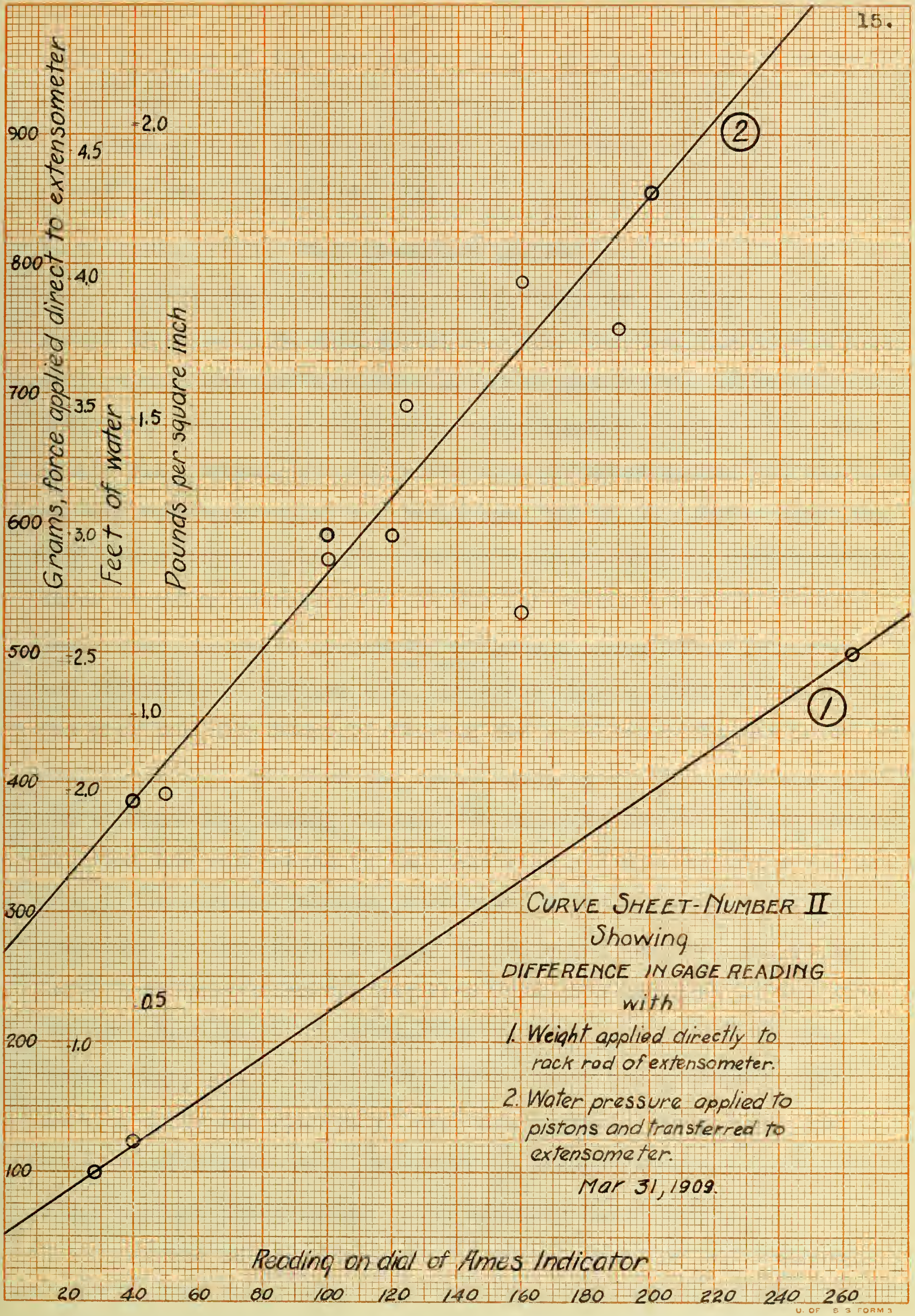
Readings taken in the calibration of the Ames Extensometer which was used with the first tests on diaphragms.

Applied weight in grams.	Dial reading Ames dial.
50	1.50
60	8.50
80	15.00
100	28.50
120	47.00
130	46.00
140	47.50
150	58.00
160	68.00
170	67.00
180	67.50
190	75.00
200	75.50
210	85.00
220	95.00
230	99.00
240	100.00
250	107.00
260	115.00


CURVE SHEET NUMBER I
Showing
CALIBRATION CURVE
for
EXTENSOMETER
L.A.M. No. 664
Feb. 4, 1909.
Reading on dial of Ames Indicator
Weight in grams on rack rod.
0
10
20
30
40
50
60
70
80
90
100
120
130
140
150
0
20
40
60
80
100
120
140
160
180
200
220
240
260

two columns. Water from the standpipe was let into the columns until the desired height was secured, then it was shut off leaving the two columns with the same pressure head. The mercury column was connected with the up stream cylinder and the water column was connected with the down stream cylinder. The height of the water column was lowered gradually until there was a definite movement recorded on the dial. It required at least 0.6 of one pound per square inch difference between the heights of the columns before there was any difference recorded on the dial. Several readings above this were taken and the readings were plotted on curve sheet No. II, on which the calibration curve of the extensometer is also placed. By a study of the curve sheet it is seen that the curve secured with the use of the pistons does not come reasonably close to the calibration curve. The ordinates measured by the distance between these two curves evidently indicates the amount of friction in the pistons that had to be overcome.

A few days later this test was again made, but we could get no readings which came reasonably close to the ones taken on the previous day. It was the opinion of the writers that if this curve could be relied upon, an allowance for the friction could be made in our final calibration for the dial. Several more attempts were made but no results could be secured that would corroborate our assumption. It was then concluded that the first trouble of getting readings opposite from those desired was due to the binding of the pistons, and that it was impracticable to obtain a smooth and almost frictionless motion with the steam indicator piston apparatus as we were using it. However, the writers believe that the theory of the piston device might prove to be practicable and if more time

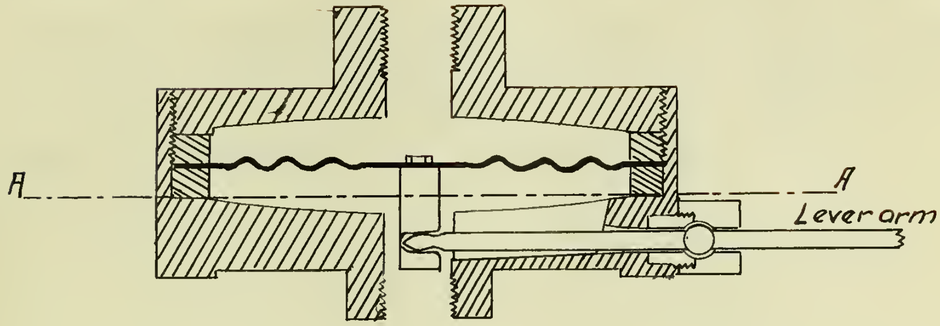

Grams, force applied direct to extensometer
Feet of water
Pounds per square inch
900
800
700
600
500
400
300
200
100
4.5
4.0
3.5
3.0
2.5
2.0
1.0
2.0
1.5
1.0
0.5
2
1
Curve Sheet-Number II
Showing
DIFFERENCE IN GAGE READING
with
1. Weight applied directly to rack rod of extensometer.
2. Water pressure applied to pistons and transferred to extensometer.
Mar 31, 1909.
Reading on dial of Ames Indicator
20 40 60 80 100 120 140 160 180 200 220 240 260

could be given to the perfection of the design, the troubles which arose might be eliminated and then satisfactory results obtained. It seemed best to Professor Sanborn that the use of the pistons be abandoned and a new device tried.

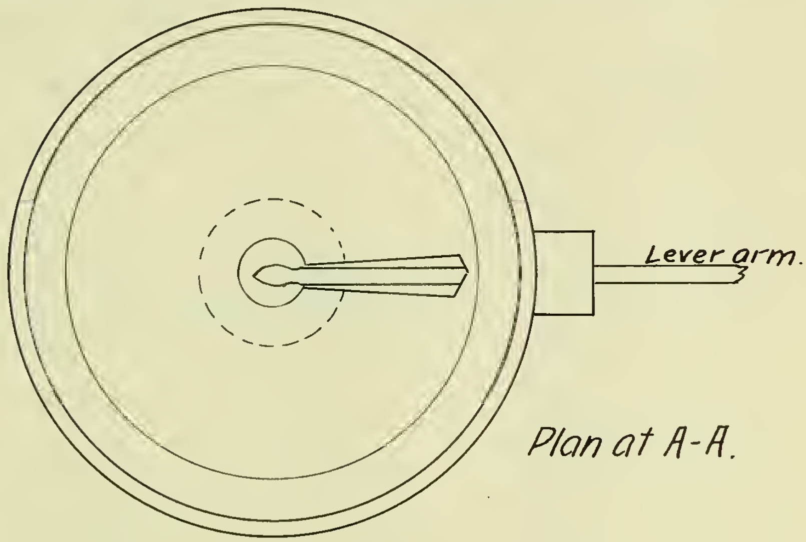
THE DIAPHRAGM THEORY

Along this line he had constructed for our tests a diaphragm apparatus. By this apparatus, with the high pressure acting against one side and the lower pressure against the other side, a flexural motion of the diaphragm would result. The amount of this motion will depend upon the difference in pressure and the elasticity and corrugations of the diaphragm. The first form of diaphragm used was a copper disk, two and one fourth inches in diameter with three circular corrugations. It was set within a hollow circular brass case, as shown in drawing on page 17. One end of the case was threaded and screwed into the other part so that the edge of the disk was held securely between two shoulders. The motion of the central part of the disk was transferred by a lever, which was fitted with a ball-bearing fulcrum, to the rack rod of the extensometer that was calibrated in the test with pistons. We had six diaphragms of various thicknesses and the above tests were made on diaphragm No. 1, which was made of copper of gage No. 37. It was found that this diaphragm was very sensitive and that it was useful for differences of pressure up to about 0.7 of a pound per square inch, but at this point the movement was limited by the case. A curve was plotted of the results that we obtained, see curve sheet No. III. Repeated tests gave readings which were fairly close but not close enough to be entirely satisfactory.

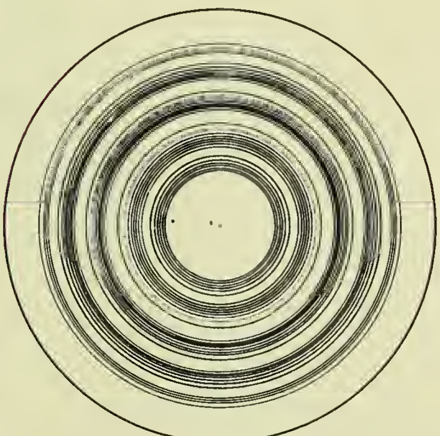
A new method for measuring the movement of the diaphragm



Cross Section of brass case, holding diaphragm



Plan of brass case

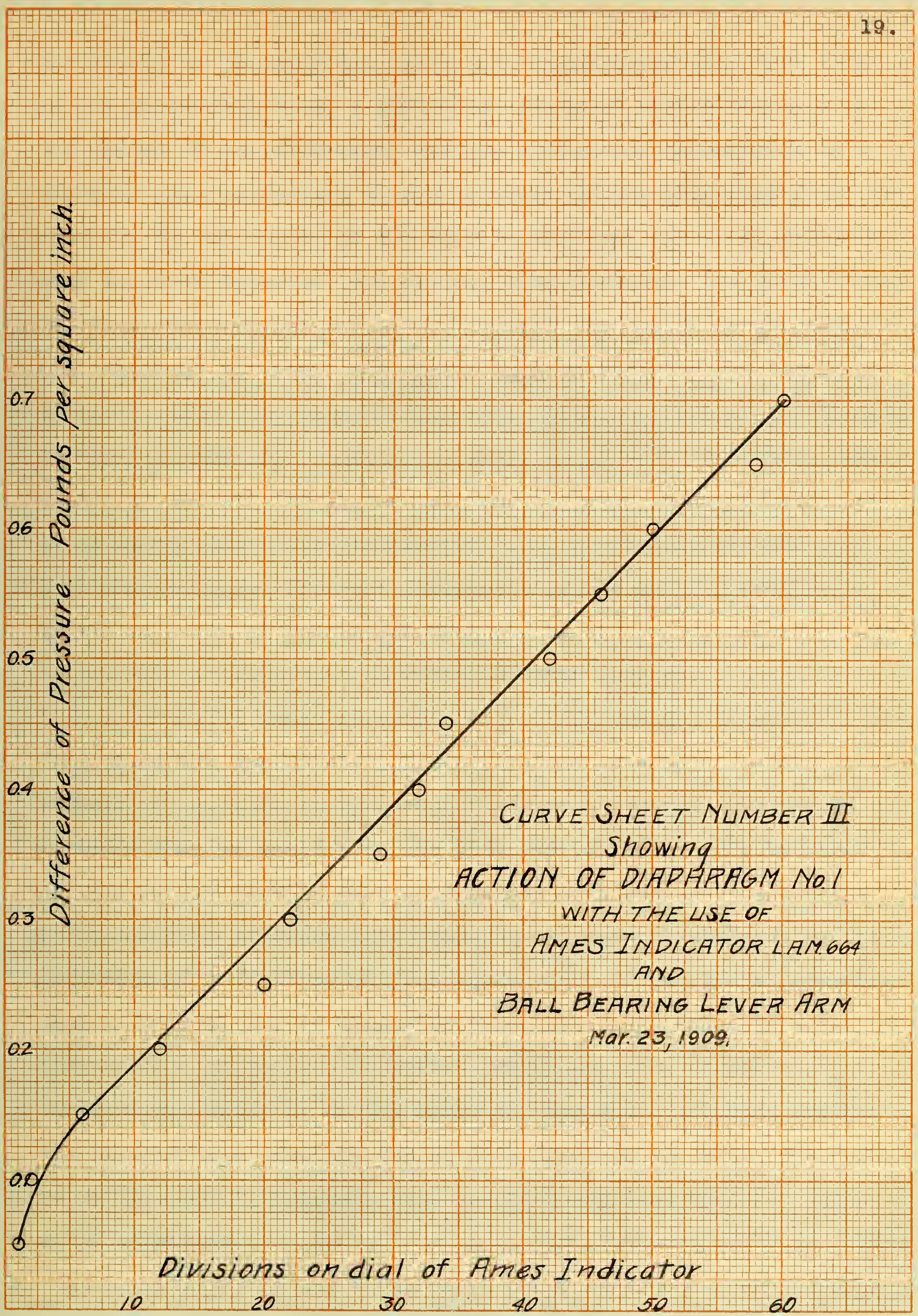


Plan of $2\frac{1}{4}$ inch diaphragm.

Data Sheet No. 2.

Readings taken in the test on Diaphragm No.1, which is a copper, circular corrugated disk, two and one-fourth inch in diameter. A ball-bearing lever arm and an Ames extensometer were used to measure the movement of the diaphragm.

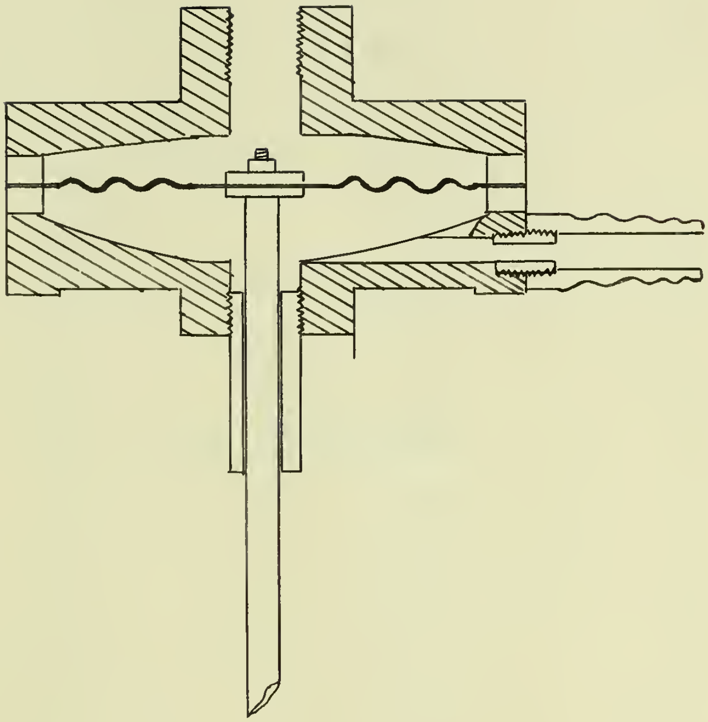
Difference of pressure. Pounds per square inch.	Divisions on dial of Ames indicator.
0.05	1
0.10	2
0.15	6
0.20	12
0.25	20
0.30	22
0.35	29
0.40	32
0.45	34
0.50	42
0.55	46
0.60	50
0.65	58
0.70	60



U. OF I. S. S. FORM 3

was tried. In place of the lever and extensometer that were used in the preceeding test, a piston was fastened perpendicularly to the center of the diaphragm and its motion was transferred to a pressure gage mechanism; thus a movement of the diaphragm could be observed by the travel of the hand in the same way as an ordinary gage would be observed. The piston, that prevented the water escaping from the case and served to transmit the motion to the mechanism, was made of steel, one-eighth inch in diameter and carefully machined, and it corresponded closely with the form of piston that is used in hydraulic indicators. Also, as in such indicators, the sleeve to receive the piston was made of brass and carefully reamed so as to caused very little friction. The amount of this friction can be judged from the subsequent curves by the pressure required to cause an initial reading and by the sensitiveness of the tests. See sketch of piston arrangement on page 21.

The next tests were made with diaphragm No. 3, gage No. 36. This diaphragm was stiffer, making it less sensitive to small differences of pressure, but we could test with greater differences of pressure than we could with the previous diaphragm. A curve was plotted of the results that we obtained with the above diaphragm and mechanism. It shows this diaphragm to have a much greater movement between 2 and 3 pounds per square inch difference of pressure than at others, and it should be noted that this characteristic in the curve is noticeable throughout the succeeding diaphragm tests. The question arose as to the cause of this characteristic and it was thought that possibly the elastic limit of the metal was reached at this point. However, this question was left open for subsequent attention.

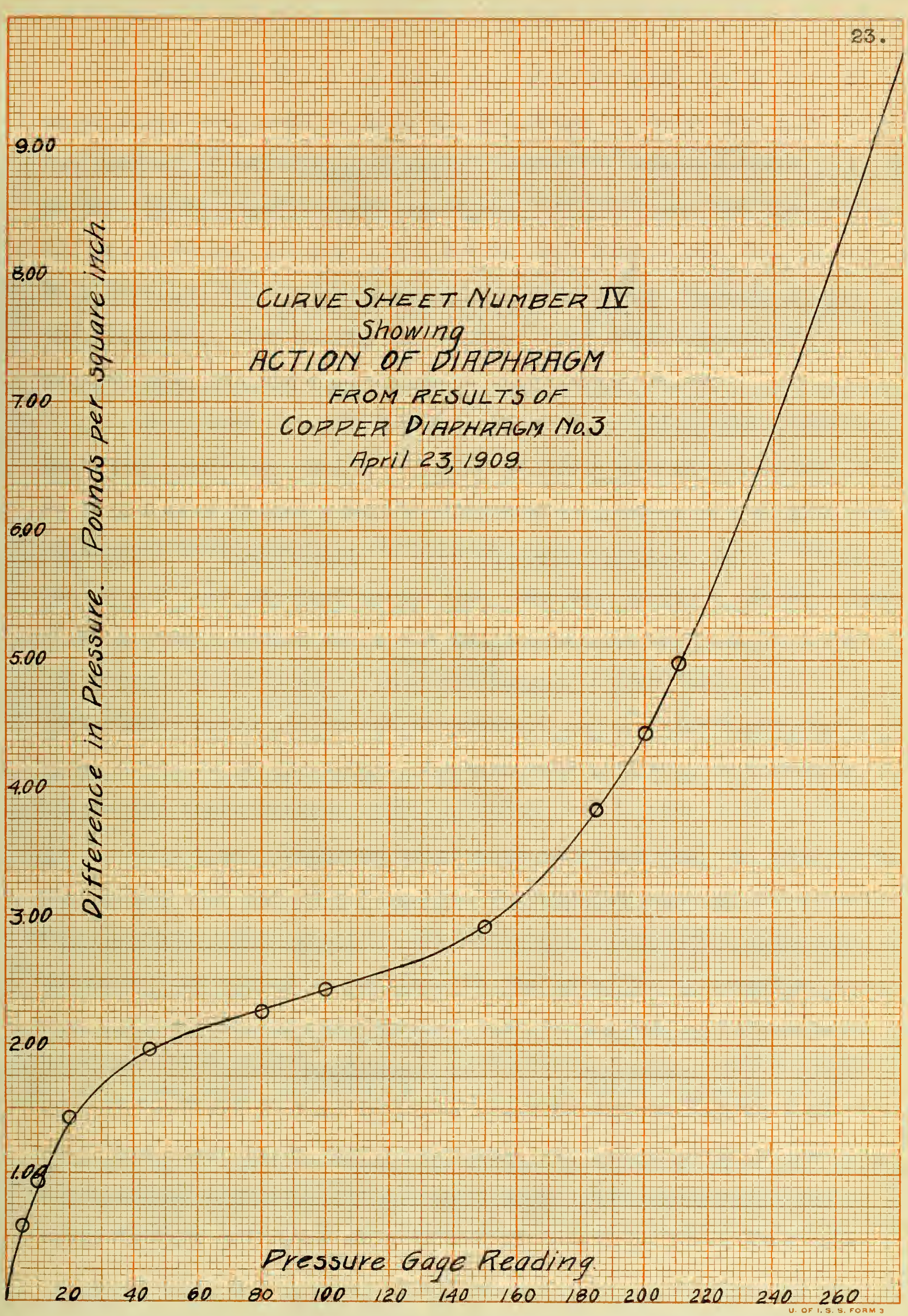


Sketch of Piston Arrangement
as used with $2\frac{1}{2}$ inch diaphragm.

Data Sheet No. 3.

Readings taken in tests on Diaphragm No. 3, which is a circular, corrugated copper disk, two and one-fourth inches in diameter. A perpendicular piston and pressure gage mechanism were used to measure the movement.

Mercury column. Pounds per square inch.	Water column. Pounds per square inch.	Difference of pressure. Lbs. per Sq. In.	Gage Reading.
7.98	7.98	0.00	0
7.39	7.98	0.59	5
7.05	7.98	0.93	10
6.54	7.97	1.43	20
6.35	7.97	1.62	25
6.00	7.96	1.96	45
5.70	7.95	2.25	80
5.57	7.94	2.37	90
5.48	7.93	2.45	100
5.20	7.92	2.72	130
5.10	7.92	2.82	143
5.00	7.91	2.91	150
4.81	7.91	3.10	160
4.40	7.90	3.50	173
4.05	7.89	3.84	185
3.45	7.88	4.43	200
0.00	7.86	7.86	265


CURVE SHEET NUMBER IV
Showing
ACTION OF DIAPHRAGM
FROM RESULTS OF
COPPER DIAPHRAGM No. 3
April 23, 1909.
Difference in Pressure. Pounds per square inch.
Pressure Gage Reading
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
20
40
60
80
100
120
140
160
180
200
220
240
260

Diaphragm No. 4 was next put into the case and a pair of steel rings were used to hold the diaphragm in place and also for the purpose of allowing a greater movement of the diaphragm. Attempts were made to carry out a complete test but for some reasons the pressure columns could not be kept stationary long enough to finish the test. This was probably due to some leakage around the diaphragm. The one set of readings that were obtained were used to make the curve as shown on curve sheet No. V.

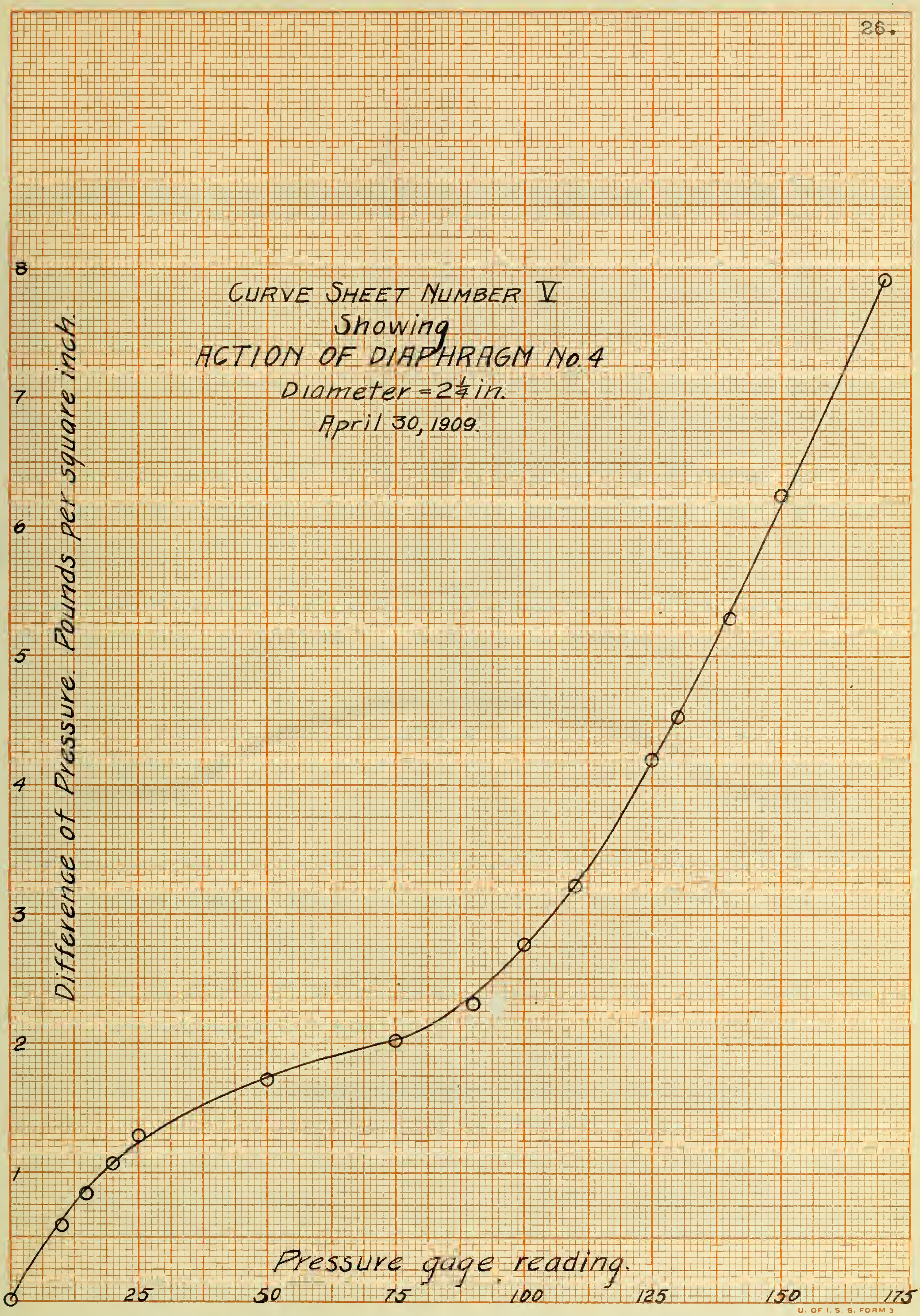
The remaining two and one-quarter inch diaphragms were not tested as Professor Sanborn decided to try a larger diaphragm, so as to obtain a larger range in difference of pressure and make the instrument more sensitive. A special cast iron case was obtained that would take six-inch diaphragm. This gave a total pressure area of 28.3 square inches while the two and one-fourth inch diaphragm had given a total area of only 4.0 square inches. Thus it will be seen that a given difference of pressure would cause a greater total pressure on the larger diaphragm and a greater movement of its center would result.

The first diaphragm tried with this new case was made of soft rubber and was of a form that is used for regulators in heating apparatus. The sketch on page 27 shows the general shape and the method of making connections in the case. We succeeded in getting only one set of results that were in any way satisfactory, although the rubber diaphragm at first seemed very promising. The results of this test are plotted on curve sheet No. VI. It can be seen from this curve sheet that no movement was transferred to the dial until we had a pressure of 0.3 of a pound per square inch. The cause for our not being able to get any readings lower than this

Data Sheet No. 4.

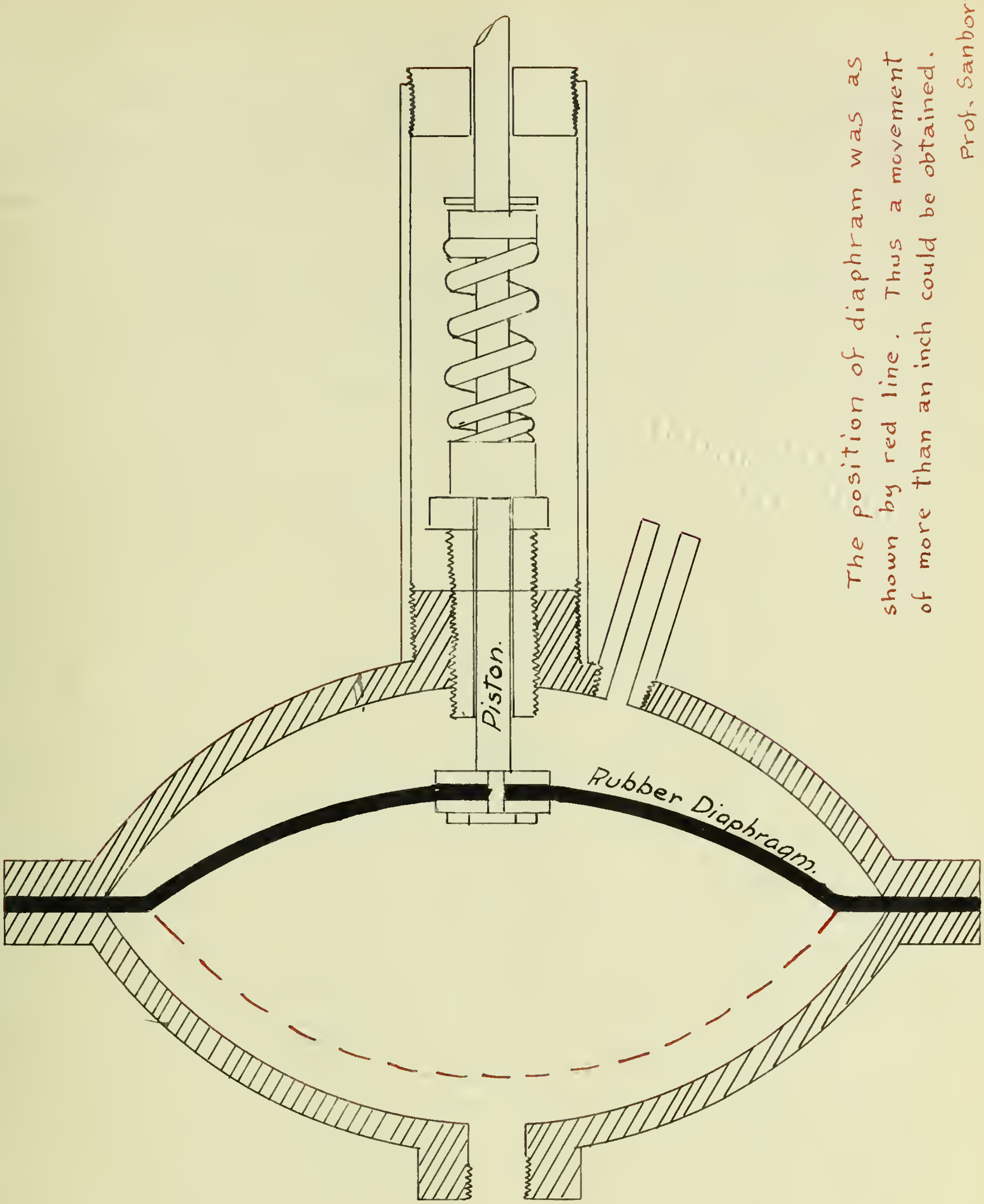
Readings taken in tests on Diaphragm No. 4, which is a circular, corrugated copper disk, two and one-fourth inches in diameter. A perpendicular piston and pressure gage mechanism used.

Mercury column. Pounds per square inch.	Water column. Pounds per square inch.	Difference of pressure. Lbs. per Sq. In.	Gage Reading.
8.28	8.28	0.00	0
8.26	7.68	0.58	10
8.24	7.40	0.84	15
8.21	7.14	1.07	20
8.20	6.92	1.28	25
8.15	6.44	1.71	50
8.13	6.15	2.02	75
8.10	5.80	2.30	90
8.08	5.32	2.76	100
8.06	4.85	3.21	110
8.04	3.85	4.19	125
8.02	3.50	4.52	130
7.99	2.70	5.29	140
7.98	1.74	6.24	150
7.93	0.00	7.93	170


CURVE SHEET NUMBER V
Showing
ACTION OF DIAPHRAGM No. 4
Diameter = 2¼ in.
April 30, 1909.
Difference of Pressure. Pounds per square inch.
Pressure gage reading.
1
2
3
4
5
6
7
8
25
50
75
100
125
150
175

The position of diaphram was as shown by red line. Thus a movement of more than an inch could be obtained.

Prof. Sanborn

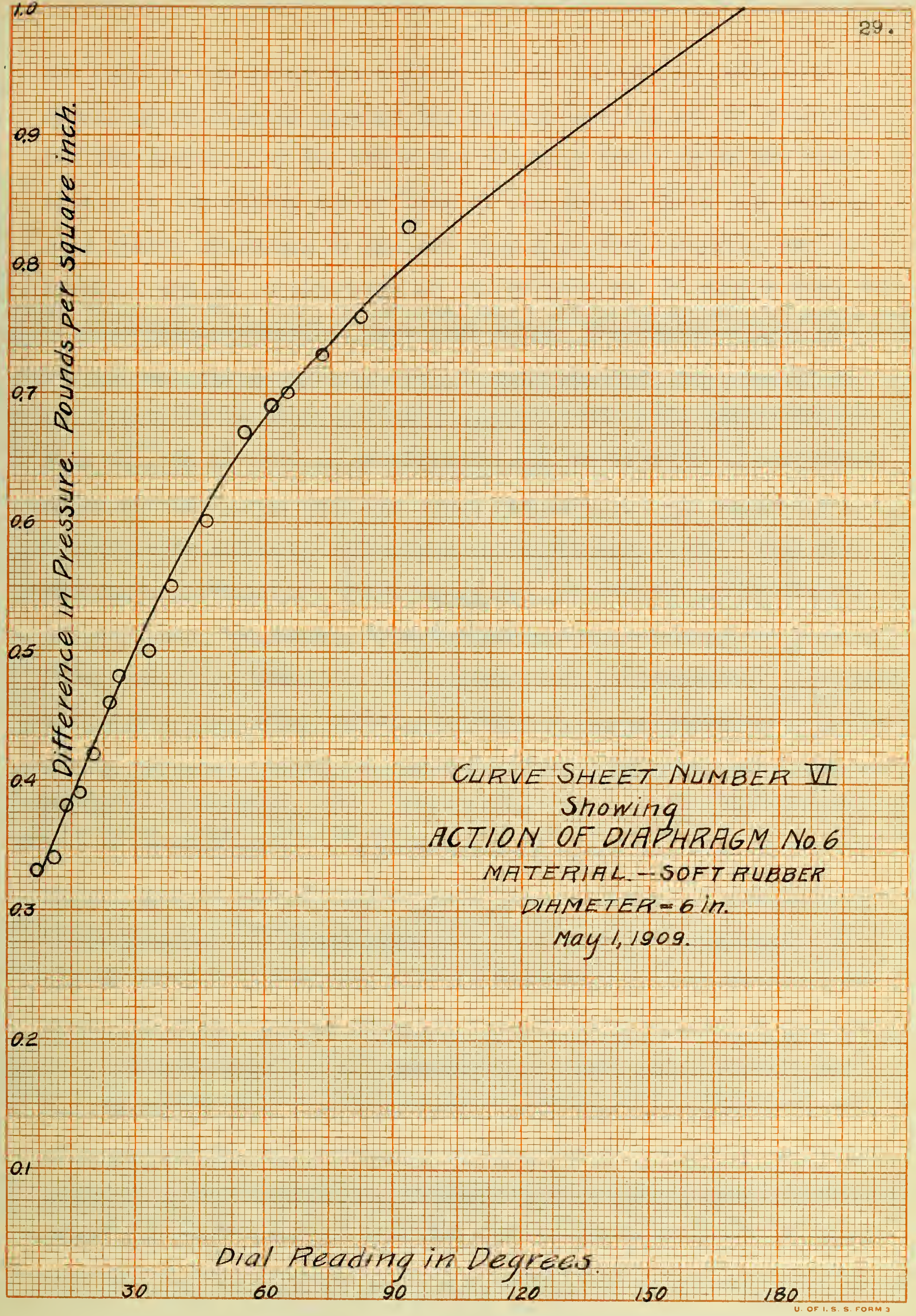


Sketch showing Rubber Diaphragm cast-iron case and piston connection.

Data Sheet No. 5.

Readings taken from test on a soft rubber diaphragm. The diaphragm was saucer shaped and six inches in diameter. The movement was registered on a dial which was divided into degrees.

Difference of pressure. Pounds per square inch.	Dial readings in degrees.
0.33	7
0.34	11
0.38	14
0.39	17
0.42	20
0.46	24
0.48	26
0.50	33
0.55	38
0.60	46
0.67	55
0.69	61
0.70	65
0.73	73
0.76	82
0.83	93
1.02	179


Difference in Pressure. Pounds per square inch.
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Dial Reading in Degrees.
30
60
90
120
150
180
CURVE SHEET NUMBER VI
Showing
ACTION OF DIAPHRAGM No 6
MATERIAL.—SOFT RUBBER
DIAMETER = 6 in.
May 1, 1909.
U. OF I. S. S. FORM 3

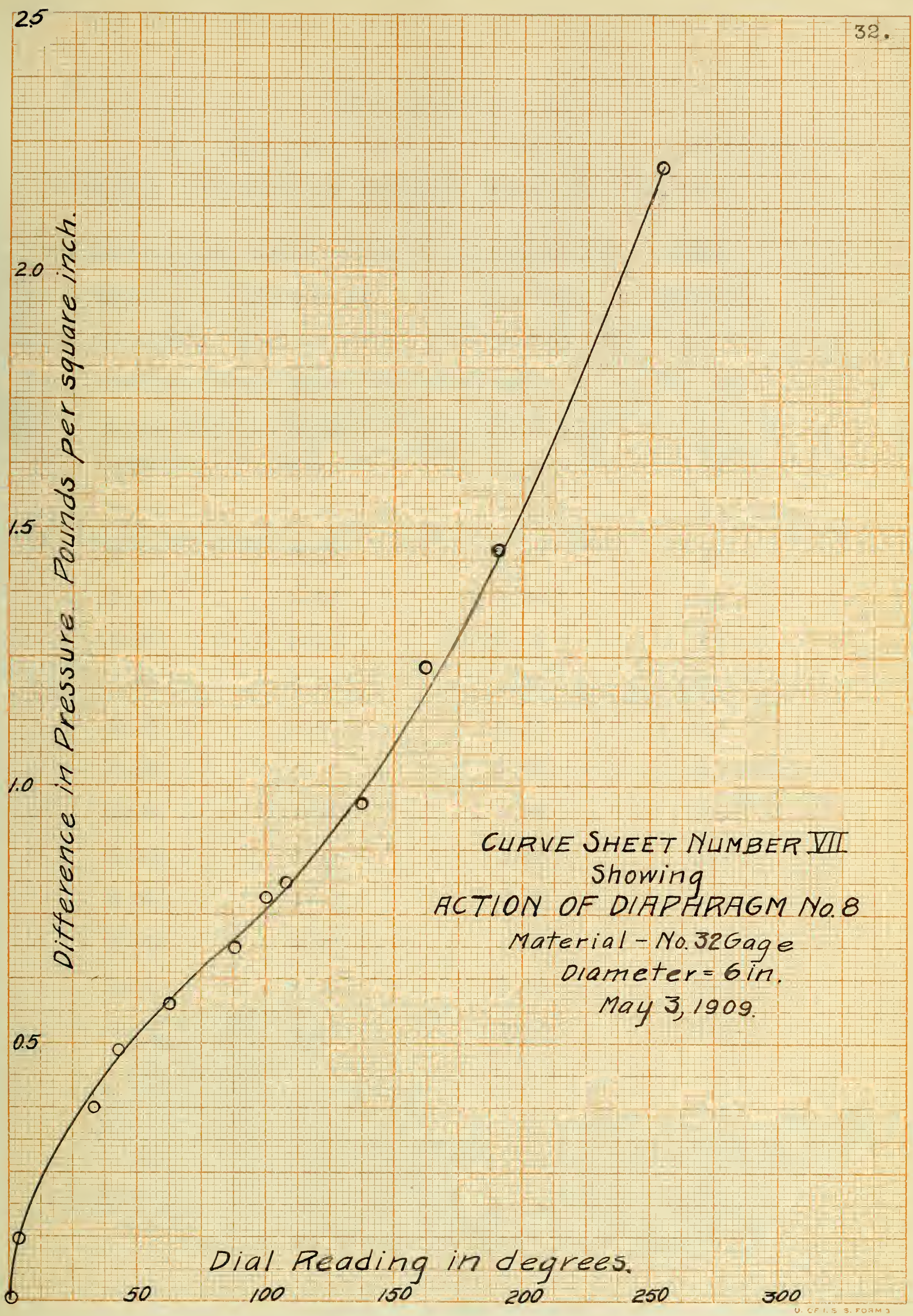
was laid to the great flexibility of the rubber. As indicator spring acted lightly against the central portion of the diaphragm, but the pressure of the water was probably taken up by the elasticity of the rubber rather than by the spring. From the test on this rubber diaphragm we decided that a stiffer material was desirable, and so a diaphragm of tin of gage No. 32 with a flat surface and no corrugations, was next tried. The table of data on page 31 and curve sheet No. VII on page 32 shows the results of this test. It is seen that this curve has the same characteristic that existed in all our diaphragm tests. At first this test seemed to be coming out with very good results, but the apparatus got out of order and upon taking out the diaphragm it was found that the center part of the diaphragm where the connection to the piston was made, had become broken. This connection had been made by placing a brass washer on each side of the diaphragm and fastening with a nut. The metal around the edges of these washers was not strong enough to stand the pressure brought upon it, and it sheared off.

Diaphragm No. 9 was of the same shape and size as No. 8, except that it was of lighter material; this was for the purpose of getting more delicate readings. This time rubber gaskets were placed between the washers and the diaphragm at the rod connections. The data obtained from the test of diaphragm No. 9 is given in a table on page 33, and the curve on curve sheet No.VIII, plotted from this data indicates practically the same results as those of diaphragm No. 8. Professor Sanborn was not entirely satisfied with the action of the tin diaphragm and he next procured a bronze diaphragm with circular corrugations. It was made of No. 30 gage

Data Sheet No. 6.

Data taken from tests on Diaphragm No. 8, which was a tin diaphragm six inches in diameter. Its surface was flat and was without corrugations. Made of 32 gage tin.

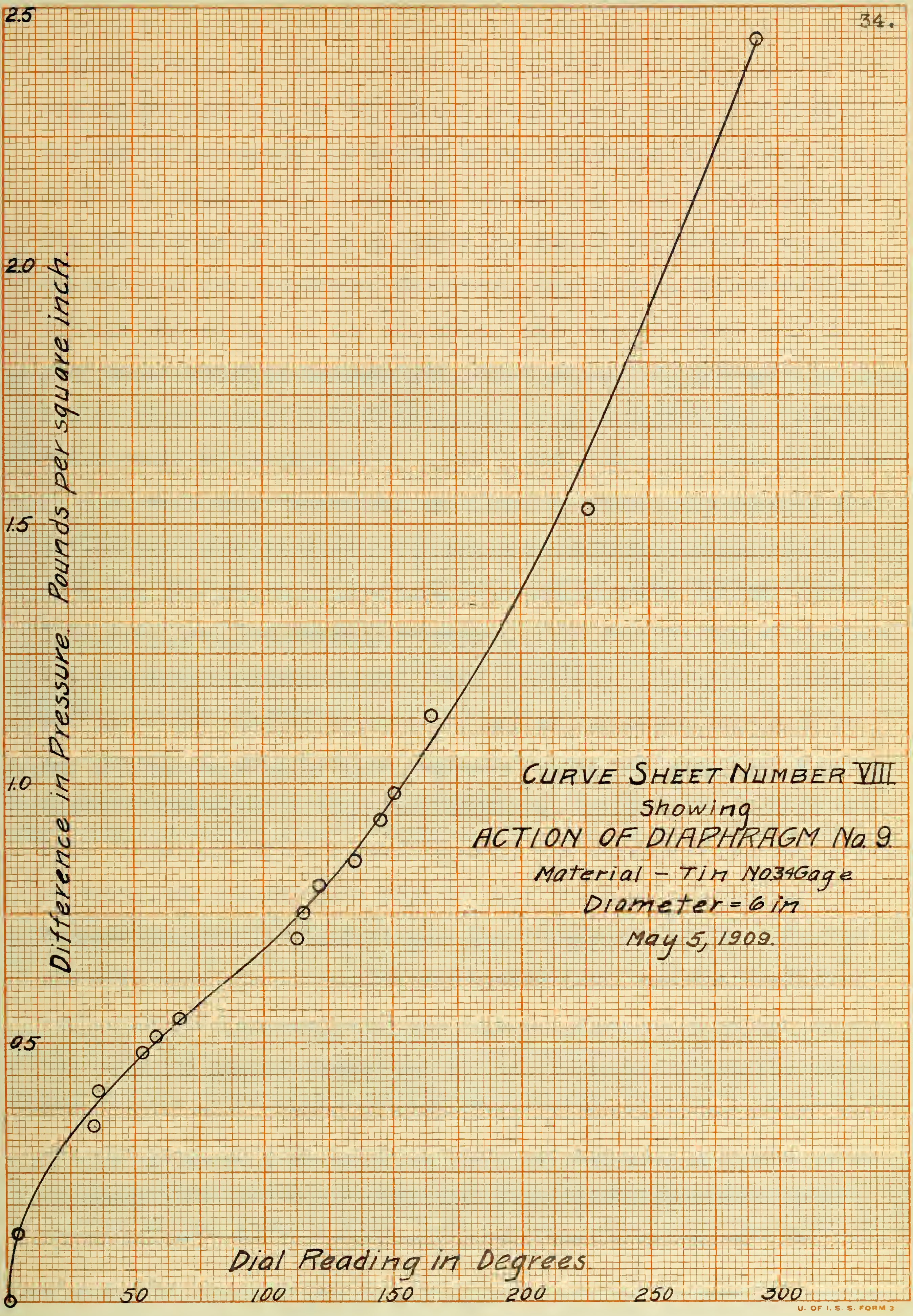
Mercury column. Pounds per square inch.	Water column. Pounds per square inch.	Difference of Pressure. Lbs. per Sq. In.	Gage Reading. Degrees.
7.90	7.90	0.00	1
7.89	7.77	0.12	4
7.88	7.50	0.38	33
7.86	7.37	0.49	43
7.85	7.28	0.57	62
7.84	7.15	0.69	88
7.82	7.03	0.79	100
7.80	6.99	0.81	108
7.79	6.83	0.96	137
7.78	6.55	1.23	162
7.76	6.31	1.45	190
7.75	5.35	2.40	255


2.5
2.0
1.5
1.0
0.5
Difference in Pressure. Pounds per square inch.
Dial Reading in degrees.
50
100
150
200
250
300
CURVE SHEET NUMBER VII
Showing
ACTION OF DIAPHRAGM No. 8
Material - No. 32 Gage
Diameter = 6 in.
May 3, 1909.

Data Sheet No. 7.

Data taken from tests on Diaphragm No. 9, which was a tin diaphragm six inches in diameter, and of No. 34gage.

Mercury column. Pounds per square inch.	Water column. Pounds per square inch.	Difference of pressure. Lbs. per Sq. In.	Gage Reading. Degrees.
6.00	6.00	0.00	1
5.95	5.82	0.13	5
5.85	5.51	0.34	34
5.79	5.38	0.41	36
5.70	5.22	0.48	53
5.68	5.17	0.51	58
5.62	5.07	0.55	67
5.40	4.70	0.70	113
5.37	4.62	0.75	115
5.33	4.53	0.80	122
5.28	4.42	0.86	135
5.22	4.29	0.93	145
5.20	4.22	0.98	151
5.13	4.07	1.14	165
4.91	3.38	1.53	226
4.63	2.19	2.44	292



2.5
2.0
1.5
1.0
0.5
50
100
150
200
250
300
Difference in Pressure. Pounds per square inch.
Dial Reading in Degrees.
CURVE SHEET NUMBER VIII
Showing
ACTION OF DIAPHRAGM No. 9.
Material - Tin No34 Gage
Diameter = 6 in
May 5, 1909.
U. OF I. S. S. FORM 3

special bronze and was carefully corrugated, or "spun" as the manufacturers call it, by the Powers Regulator Company of Chicago. Instead of fastening the piston to the diaphragm by making a hole in it and using washers and nut, as had been done previously, it was decided in this case to allow the end of the piston to rest directly on the diaphragm. Therefore, there being no connection through the center of the diaphragm, any possible leakage from that cause would be stopped and, furthermore, any tendency for the piston to be forced out of alignment by a rigid fastening as formerly, would be obviated.

With this diaphragm, as with the others, the data in the tables was taken with only the pressure columns working and not with the difference of pressure obtained by using the two Pitot Tube openings. The mercury column was used for the higher pressure and the water column for the lower. A stiffer spring for the diaphragm to act against was put in, and by the adjusting screw on the piston, as much tension could be put on the spring as was thought necessary. A 20 -pound spring was used in connection with this diaphragm. After several trials, the tension which was needed to bring the pointer just back to zero was found, and a test was carried on with it adjusted that way. The greatest difference of pressure used was 3.7 pounds per square inch, and this caused a deflection of the needle of 242 degrees. Then the pressure on the two sides of the diaphragm was allowed to equalize and the pointer came rather slowly back to zero. This latter fact was a very important point that we had been unable to accomplish in the tests of any of the previous diaphragms. Four trials were made under these conditions, and the accompanying tables and curve sheet No9.

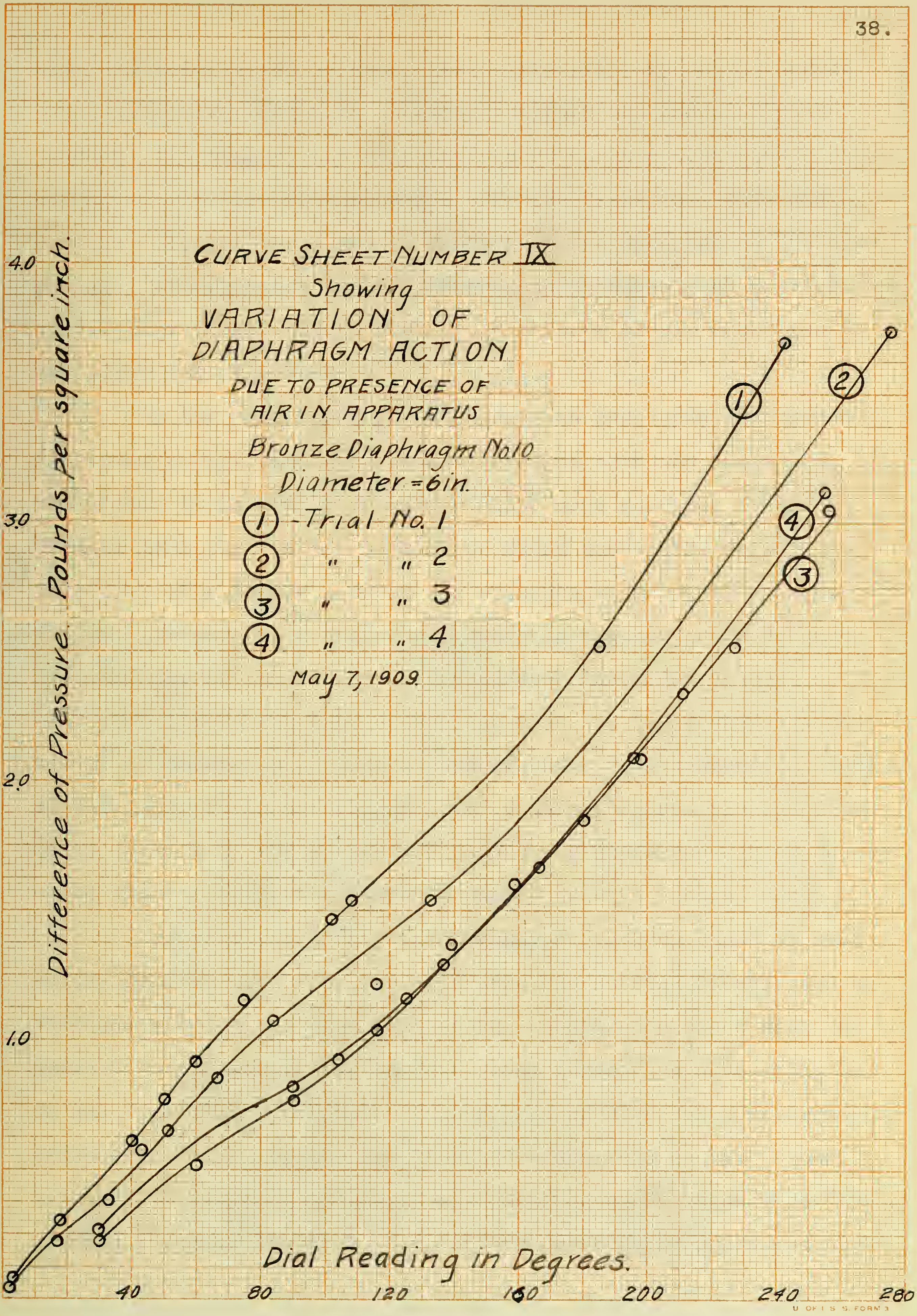
Data Sheet No. 8.

Data taken in four trial tests on the circular , corrugated bronze diaphragm.

Mercury column. Pounds per square inch.	Water column. Pounds per square inch.	Difference of pressure. Lbs, per Sq. In.	Dial Reading Degrees.
Trial No. 1.			
6.68	6.60	0.08	3
6.60	6.30	0.30	18
6.51	5.90	0.61	40
6.46	5.70	0.77	50
6.41	5.50	0.91	60
6.35	5.20	1.15	75
6.23	4.70	1.53	108
5.97	3.45	2.52	185
5.78	2.08	3.70	242
Trial No. 2.			
7.76	7.72	0.04	2
7.69	7.47	0.22	17
7.65	7.27	0.38	33
7.58	7.00	0.58	43
7.55	6.90	0.65	51
7.51	6.70	0.81	63
7.44	6.37	1.07	84
7.34	6.12	1.22	116
6.94	3.25	3.69	275

Data Sheet No. 8, (Continued).

Mercury column. Pounds per Square inch.	Water column. Pounds per Square inch.	Difference of pressure. Lbs. per Sq. In.	Dial Reading Degrees.
Trial No. 3.			
7.03	6.75	0.28	30
6.82	6.00	0.82	90
6.80	5.87	0.93	104
6.76	5.72	1.04	115
6.73	5.57	1.16	125
6.69	5.32	1.37	139
6.62	5.02	1.60	159
6.57	4.72	1.85	180
6.51	4.42	2.09	198
6.44	3.92	2.52	227
6.36	3.31	3.05	256
Trial No. 4.			
7.80	7.57	0.23	30
7.69	7.17	0.52	60
7.59	6.82	0.77	90
7.52	6.47	1.04	115
7.46	6.17	1.29	136
7.38	5.72	1.66	166
7.32	5.22	2.10	196
7.26	4.92	2.34	211
7.16	4.05	3.11	255


CURVE SHEET NUMBER IX
Showing
VARIATION OF
DIAPHRAGM ACTION
DUE TO PRESENCE OF
AIR IN APPARATUS
Bronze Diaphragm No.10
Diameter = 6 in.
1 - Trial No. 1
2 " " 2
3 " " 3
4 " " 4
May 7, 1909.
Difference of Pressure. Pounds per square inch.
Dial Reading in Degrees.
4.0
3.0
2.0
1.0
40
80
120
160
200
240
280
1
2
3
4

show the results. It is seen, that while all four of the curves are very similar and have a tendency toward the curves for the previous diaphragms, the last two curves in this test give a much greater deflection of the needle than the first two. This difference was thought to be due to fatigue of the material in the diaphragm, but Professor Sanborn afterwards concluded, as a result of tests, that it was due to misleading effects of air pressures in the pipes and apparatus.

On the next day a similar test was made upon the bronze diaphragm except that more tension was put upon the spring, so that the needle would come back to zero much more quickly. It was thought that this increased tension would enable the spring to take care of a larger part of the pressure than before and thus relieve the stress on the diaphragm. Five trials were made this time and the tables and curve sheet No. X show the results. It is seen that the curves come closer together, in fact, they are near enough to enable us to draw a general curve to represent the action of the gage. It is not thought that within a reasonable range the extra tension on the spring would make any difference in the curve other than to bring the readings nearer to this general curve.

The results of this test seemed to be very close to what we had been seeking for. The apparatus was working nicely, and no difficulty was experienced in getting readings to check with the general curve upon making several check tests. The next thing to do was to try the instrument thus rigged up with the difference of pressure obtained by the two Pitot Tube openings in the 6-inch pipe. If readings on the gage thus obtained would check with the general curve of the last test, we had practically fulfilled the

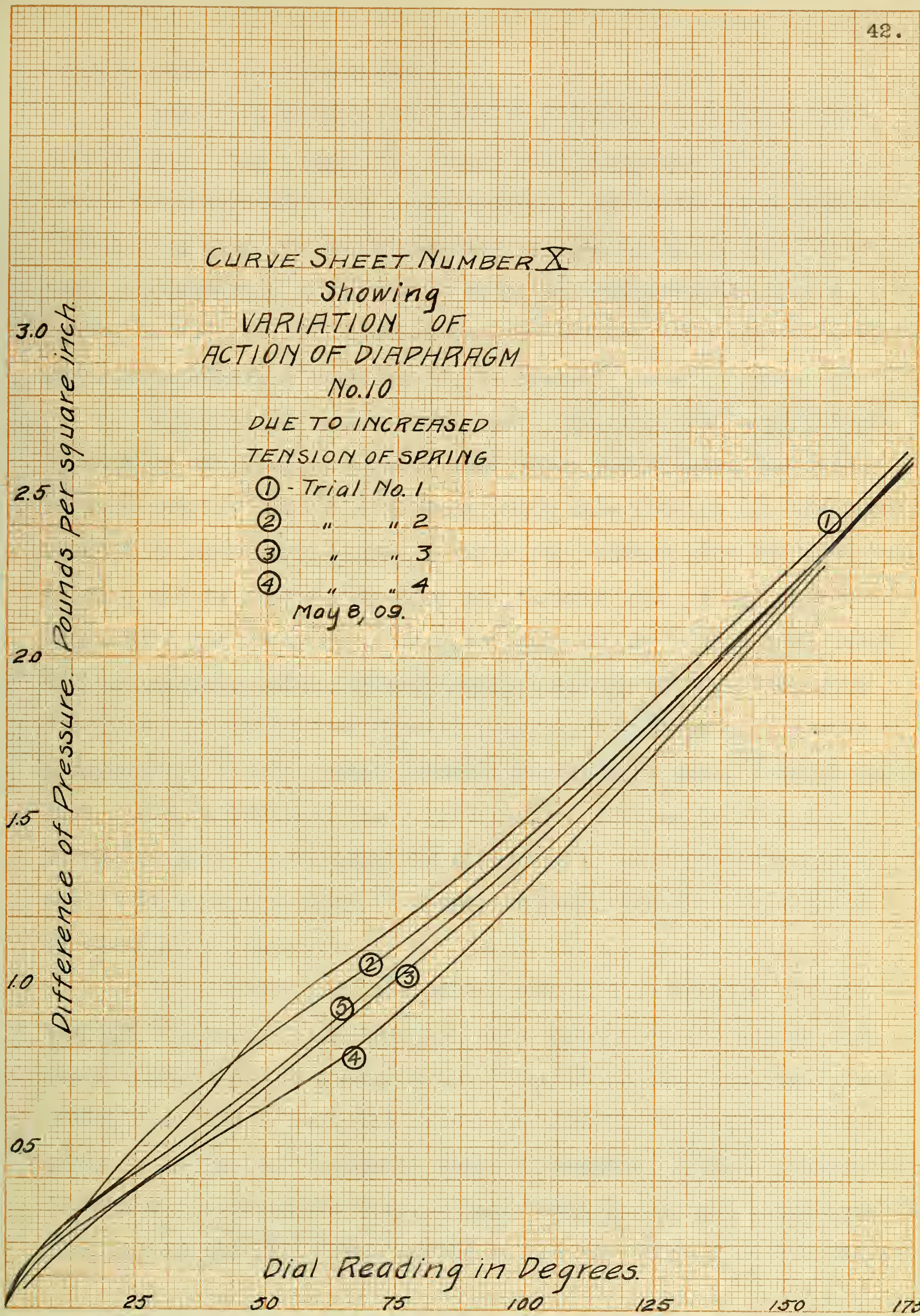
Data Sheet No. 9.

Data taken from tests on the circular, corrugated bronze diaphragm. This data was taken in the same manner a that for data sheet No. 8, but an excess tension was put upon the spring.

Mercury column. Pounds per square inch.	Water column. Pounds per square inch.	Difference of pressure. Lbs. per Sq. In.	Dial Reading Degrees.
Trial No. 1.			
7.09	7.09	0.00	0
7.05	6.99	0.06	0.5
7.03	6.85	0.18	6
7.02	6.75	0.27	11
6.92	6.07	0.85	48
6.83	5.67	1.16	74
6.73	5.17	1.56	103
6.51	3.87	2.64	173
Trial No. 2.			
7.12	7.12	0.00	0.0
7.11	7.04	0.07	0.5
7.08	6.88	0.20	8
7.05	6.73	0.32	15
6.99	6.42	0.57	29
6.90	5.97	0.93	59
6.82	5.62	1.20	81
6.76	5.27	1.49	101
6.53	3.92	2.61	174

Data Sheet No. 9, (Continued).

Mercury column. Pounds per square inch.	Water column. Pounds per square inch.	Difference of pressure. Lbs. per Sq. In.	Dial Reading. Degrees.
Trial No. 3.			
7.55	7.50	0.05	0.5
7.51	7.28	0.23	9
7.40	6.78	0.62	43
7.30	6.28	1.02	74
7.20	5.78	1.42	104
7.01	4.37	2.64	174
Trial No. 4.			
7.19	7.19	0.00	0
7.00	6.38	0.62	50
6.85	5.57	1.28	99
6.67	4.38	2.29	158
Trial No. 5.			
7.68	7.68	0.00	0
7.66	7.61	0.05	1
7.61	7.38	0.23	13
7.37	6.25	1.12	82
7.27	5.68	1.59	114
7.13	4.73	2.40	162


CURVE SHEET NUMBER X
Showing
VARIATION OF
ACTION OF DIAPHRAGM
No.10
DUE TO INCREASED
TENSION OF SPRING
① - Trial No. 1
② " " 2
③ " " 3
④ " " 4
May 8, 09.
Difference of Pressure. Pounds per square inch.
3.0
2.5
2.0
1.5
1.0
0.5
Dial Reading in Degrees.
25
50
75
100
125
150
175
①
②
③
③
④

primary object of this thesis.

The six-inch pipe was made to discharge through a four-inch nozzle. This nozzle was fitted with a piezometer ring. In the thesis work carried on by H. H. Simmons, this nozzle had been calibrated, so that for any piezometer reading on the nozzle the velocity and quantity of discharge could be read directly from a chart, as well as the simultaneous differences of pressure on the Pitot Tube openings inserted in the pipe.

The first of these final tests was made with a very small tension on the spring; namely, that which would cause the needle to move over an arc of 20 degrees. With this tension on, the needle was set to read zero. Then the water was started from the four-inch nozzle, and as soon as the pipe was flowing full, a deflection of the needle was seen. Piezometer readings on the nozzle were taken and the corresponding differences of pressure on the Pitot Tube openings were taken from Simmons' chart. With these differences of pressure the correct readings for our gage were taken from the general curve of our last test. This correct reading as well as the actual reading on the gage was placed in a table for comparison, and it is seen that they do compare fairly favorable. See table of readings on page 44.

In the next test the spring was used to turn the needle through 35 degrees, thus putting more tension on the spring when the needle is set at zero. In the last two of the final tests the spring was used to turn the needle through 72 degrees and 90 degrees . The tables on page 44 show the results of these tests. The differences between the correct gage readings and the actual gage readings in the last three tables do not vary much from the differ-

Data Sheet No. 10.

The following tables show the readings taken with the bronze diaphragm, with the four-inch nozzle running, and with different degrees of tension upon the spring.

Piezometer Reading. Lbs per Sq. In.	Difference of pressure. Lbs. per Sq. In.	Correct Gage reading. Degrees.	Actual Gage reading. Degrees.
Needle turned through 20 degrees by initial tension.			
3.10	1.00	72	72
6.00	1.84	134	133
7.50	2.38	160	157
9.00	2.88	190	187
Needle turned through 35 degrees by initial tension.			
3.10	1.00	72	72
6.00	1.84	134	134
7.50	2.38	160	162
9.00	2.88	190	192
Needle turned through 72 degrees by initial tension.			
3.10	1.00	72	78
6.00	1.84	134	136
7.50	2.38	160	162
9.00	2.88	190	193
Needle turned through 90 degrees by initial tension.			
3.10	1.00	72	72
5.00	1.62	115	113
7.00	2.25	157	154
9.00	2.88	190	187

ences in the first of the final tests. It is thought by the writers of this thesis that in the final perfection of this gage that a certain tension for the spring could be found, with which the gage would work best and give the best results.

CONCLUSION

From the results of a large number of experimental tests with various designs, it appears to us that the recording device as finally developed will prove to be suitable for indicating the flow in pipes. This development has been advanced from the steam piston idea in the beginning, to the use of a small diaphragm, and finally , to the use of a larger diaphragm. A large number of tests were made in connection with the piston idea and such a degree of success was attained that possibilities of further perfection presented themselves. However, according to our methods of experimenting the device was not a complete success. The theory seemed sound and unfaulty, and we believe that if the mechanical end would be well treated, an experimental design could be perfected. Although in a commercial form, it would probably be difficult to secure a device that would be free from friction and also one that would stay in adjustment and withstand a certain degree of rough usage.

From the tests on several small diaphragms, it was indicated that differences of pressure could be measured in that way. The diaphragms were fairly sensitive to small differences of pressure but their small size limited the movement of the piston, so that it would be necessary to multiply the movement eight or ten times, in order to record it conveniently. Therefore, the six-inch diaphragms were tried, and these gave some satisfactory results, as indicated above. As to the most suitable material of which to

make these diaphragms, it was found as result of various tests that the bronze diaphragms surpassed the copper, tin, and rubber. Besides being sensitive to small differences of pressure, even down to about 0.05 of one pound per square inch, it was also suitable for differences of pressure up to about 6.00 pounds per square inch, and had the desired elasticity. These facts showed that the assumption in favor of the larger diaphragm wa right. We cannot say that a six-inch diaphragm is better than one five inches or seven inches in diameter, but we consider it to be better than one two and one-fourth inches in diameter.

It was necessary to have a spring with some initial tension acting against the diaphragm. It was next to be decided, just what this initial tension should be to give a uniform effect upon the readings throughout the range of the gage. We have made attempt to decide this by making tests with various degrees of tension upon the spring. Enough tension was put upon the spring to secure good zero readings, and several tests were made with this as a minimun tension and with other higher tensions. The results of these tests show that variations of tension in the spring do not affect the readings much, but that the best results were obtained with the tension which would bring the hand back through an arc of 70 degrees at zero pressure.

As a final test with this experimental gage by us, the differences of pressure were measured, and the corresponding discharge from the six-inch pipe was taken from Simmons' chart. Simultaneous readings were taken on the piezometer ring and the corresponding discharge as given by Simmons checked with the quantity given by our data. That these results check, indicates that the

primary object of this thesis is accomplished, namely, to design and construct a device which would register the differences of pressure on two Pitot Tube openings, without the use of the long water or mercury columns.

APPLICATION OF DEVICE FOR INDICATING SPEED OF BOATS.

Professor Sanborn suggested that a second useful application could be made with the same apparatus for measuring the speed of boats. By placing one Pitot Tube through the bottom of a boat, or even over the side, a certain presure would result when the boat was in motion. The water pressure caused by this motion of the boat would act on one side of the diaphragm, and the atmospheric pressure on the other. By the use of a suitable indicator spring for example a 100-pound spring, the greater difference of pressure, as compared to that with the flow in pipes, could be registered on the dial the same as before.

A table was first made out showing the theoretical pressure for speeds varying from 5 to 20 miles per hour. These values were found by solving for "h" in the formula, $v=\sqrt{2gh}$, and then reducing "h" to pressure in pounds per square inch. This table is shown on page 49. From the table the values for "p" for 5 and 20 miles per hour are 0.36 and 5.80 pounds per square inch respectively. Tests were made in the laboratory with one Pitot Tube acting up stream. A circular paper dial divided into 360 degrees was used for the first experimental dial. The pressure for one mile per hour was run up on the water column, and a line drawn directly underneath the gage hand on the dial. This was repeated for pressures up to 22 miles per hour. This showed us that we had a recording device which would read accurately up to a pressure of 6.0 pounds per square inch. Although non-uniformity existed, it was good enough for actual tests on a motor-boat. Professor Sanborn made arrangements for such a test on the fast, 20 mile per hour, motor-boat, called the Meteor, owned by Walter B. Wilde of Peoria, Illinois.

Data Sheet No. 11.

Table showing the theoretical pressure for speeds varying from 5 to 20 miles per hour.

Velocity. miles per hour.	Velocity. feet per second.	Pressure "h". Feet of water.	Pressure "p". Pounds per square inch.
5	7.33	0.835	0.362
6	8.80	1.202	0.522
7	10.26	1.640	0.710
8	11.73	2.139	0.928
9	13.19	2.700	1.170
10	14.67	3.340	1.450
11	16.13	4.060	1.760
12	17.60	4.820	2.090
13	19.07	5.650	2.450
14	20.53	6.560	2.840
15	22.00	7.520	3.260
16	23.46	8.540	3.700
17	24.93	9.660	4.180
18	26.40	10.820	4.700
19	27.87	12.090	5.240
20	29.33	13.360	5.800

To render the apparatus suitable for transportation and for use in these tests, it was boxed as shown by the photograph on page 4. Before put into actual use, Professor Sanborn made a test with the Pitot Tube inserted in a nozzle stream and constructed a new dial which would represent the conditions of the apparatus as it was when ready for experiments at Peoria.

The tests were made by Professor Sanborn and Mr. Wilde over a one-mile course, and by the use of two stop watches, the actual speed in miles per hour was obtained. The speed as recorded on the dial was taken, and an allowance of five inches, or 0.4 of one foot, the distance of the diaphragm above ~~below~~ the water level was made. These results as calculated by Professor Sanborn and checked by the writers are given in table No.11 given on page 49. The readings were taken going up stream and down stream, and on two different days. The coefficient of velocity checked very closely, and the difference of the coefficients between up stream and down stream checked exactly. The average of the coefficients of velocity up stream was 0.85, and those for down stream was 0.83, making the average coefficient 0.84. The difference between the average coefficient and the coefficient up stream multiplied by the actual speed of the boat will give the velocity of the river. This value is about 0.15 miles per hour, or 0.22 feet per second, which agrees with statements made by Peoria river-men. A table of these tests made at Peoria is shown on page 51.

With the apparatus back again in the laboratory, Professor Sanborn made check tests to show that the instrument had not been thrown out of adjustment by transportation. These tests checked exactly with the ones made prior to the trip. Further tests were

Data Sheet No. 12.

Data taken from test made with boatometer at Peoria, Illinois, May 15-16, 1909, on the motor boat, called the Metior, owned by Walter B. Wilde.

Observed speed. Mi./ hr.	Corrected speed. Mi./hr.	Observed time for one mile.		Actual speed. Mi./hr.	Up or down stream.	Coefficient of velocity.
12.75	13.25	3 m	52 s	15.50	up	0.86
12.00	12.50	4	1	15.00	down	0.83
14.50	14.90	3	22	17.80	up	0.84
12.80	13.30	3	41	16.20	down	0.82
13.50	13.95	3	37	16.20	up	0.86
11.75	12.50	3	58	15.10	down	0.83
14.85	15.30	3	20	18.00	up	0.85
14.80	15.25	3	15	18.46	down	0.83

made to find what initial tension of the spring would be best suitable. Four tests of readings were taken and a comparison of the curves, shown on page 54 , can be made. The desired curves should correspond to No. 2 up to a pressure of three pounds per square inch, and approach curve No. 4 for higher pressures. This in our estimation would be an initial tension of about 70 degrees.

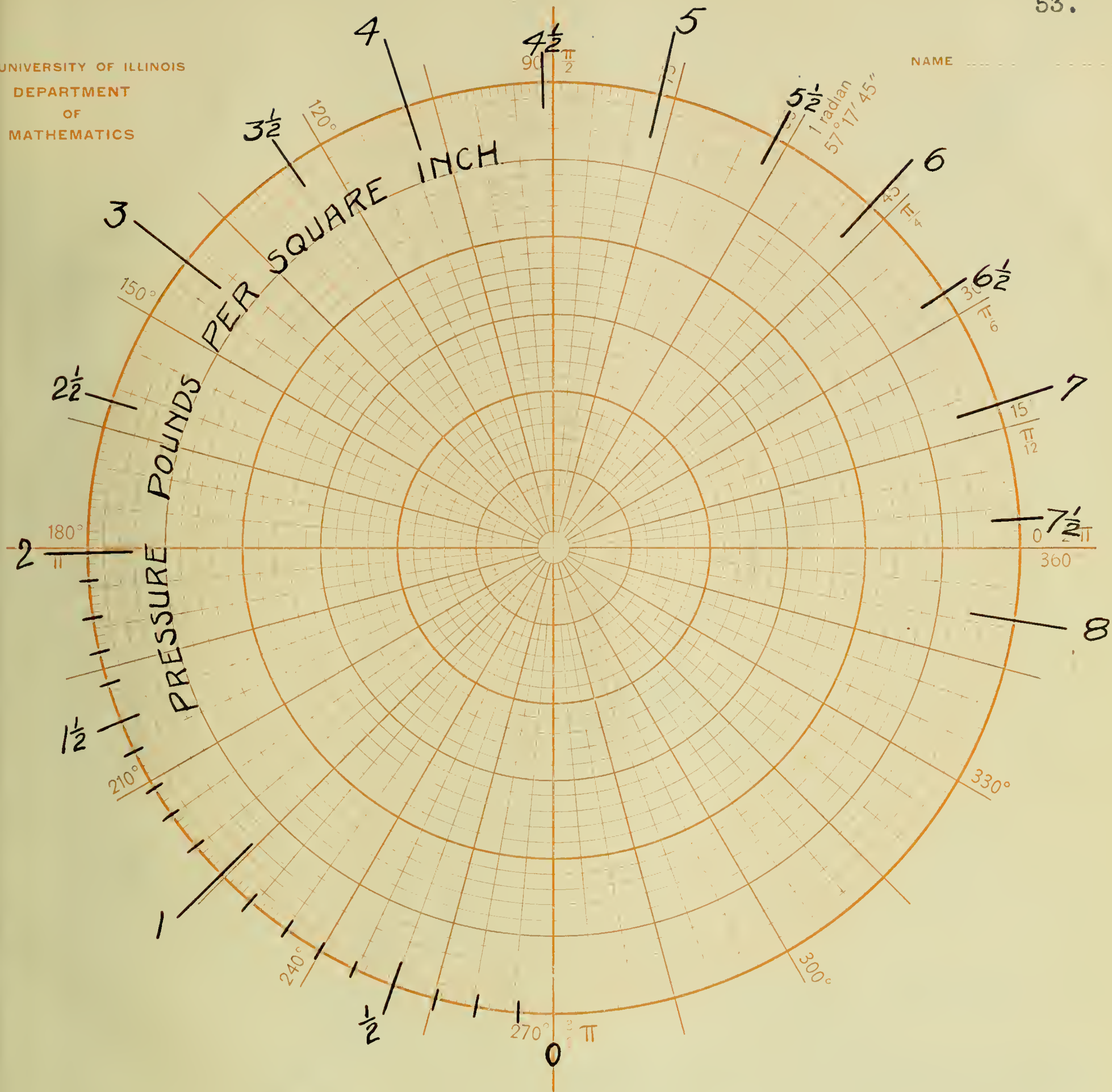
CONCLUSION

This shows one good application of the instrument. By using an initial tension of 70 degrees, and graduating a dial into divisions representing tenths of a mile per hour, and embodying a coefficient of 0.84, a dial can be obtained which will give direct readings, as shown by a plate on page 55.

The tests in the field and the laboratory tests, having proven the device to be promising, it now remains to develop minor details, and to improve the features of construction, and make it attractive for commercial purposes as a BOATOMETER.

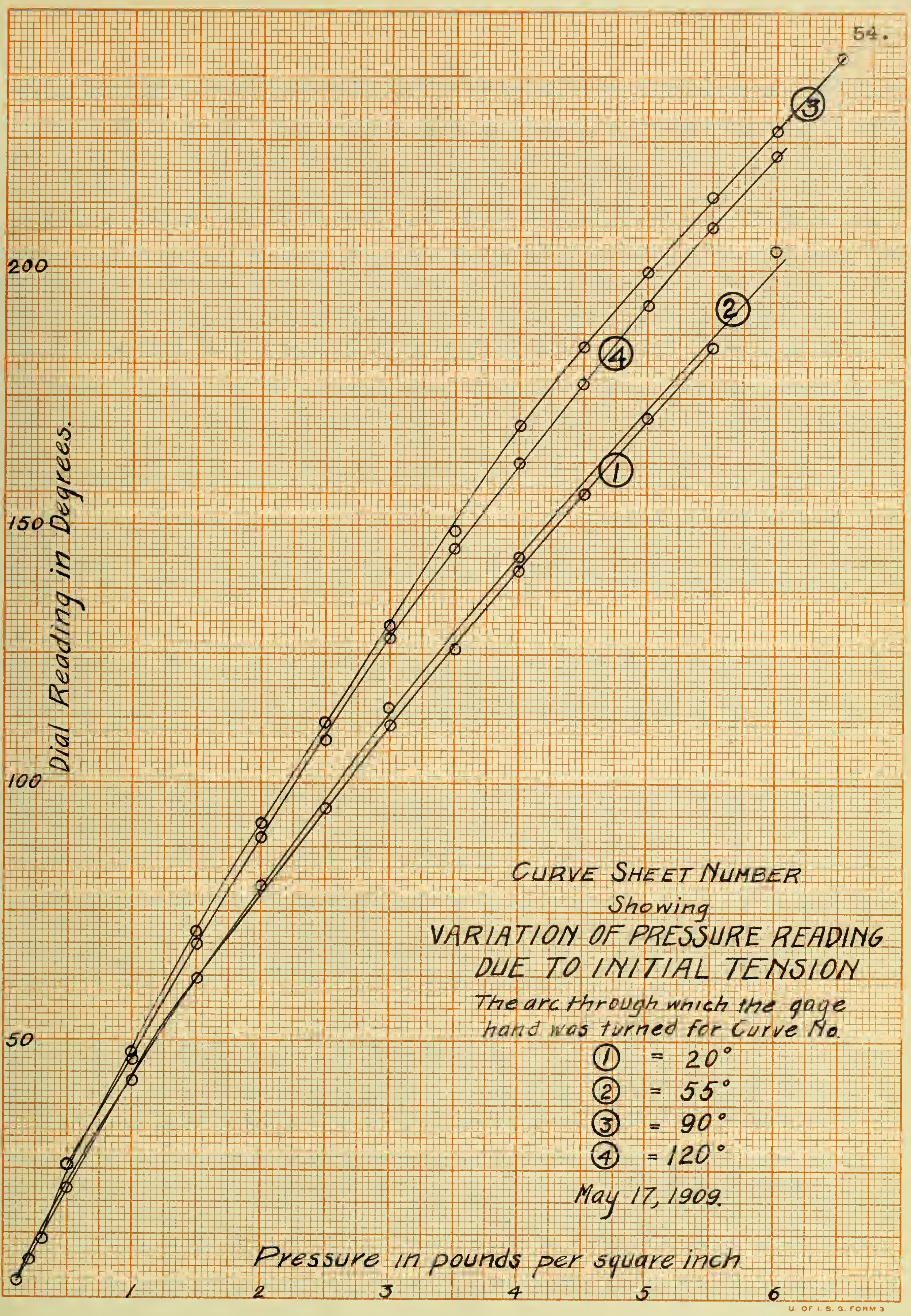
UNIVERSITY OF ILLINOIS
DEPARTMENT
OF
MATHEMATICS

NAME



TEST No. 14

SAMPLE DIAL
USED WITH
INITIAL TENSION TESTS
ON
BOATOMETER
6" Bronze Diaphragm
100 lb. Spring
Initial Tension -120°
May 17, 1909.


Dial Reading in Degrees.
200
150
100
50
Pressure in pounds per square inch
1
2
3
4
5
6
CURVE SHEET NUMBER
Showing
VARIATION OF PRESSURE READING
DUE TO INITIAL TENSION
The arc through which the gage hand was turned for Curve No.
① = 20°
② = 55°
③ = 90°
④ = 120°
May 17, 1909.
U. OF I. S. S. FORM 3

NAME . . . .

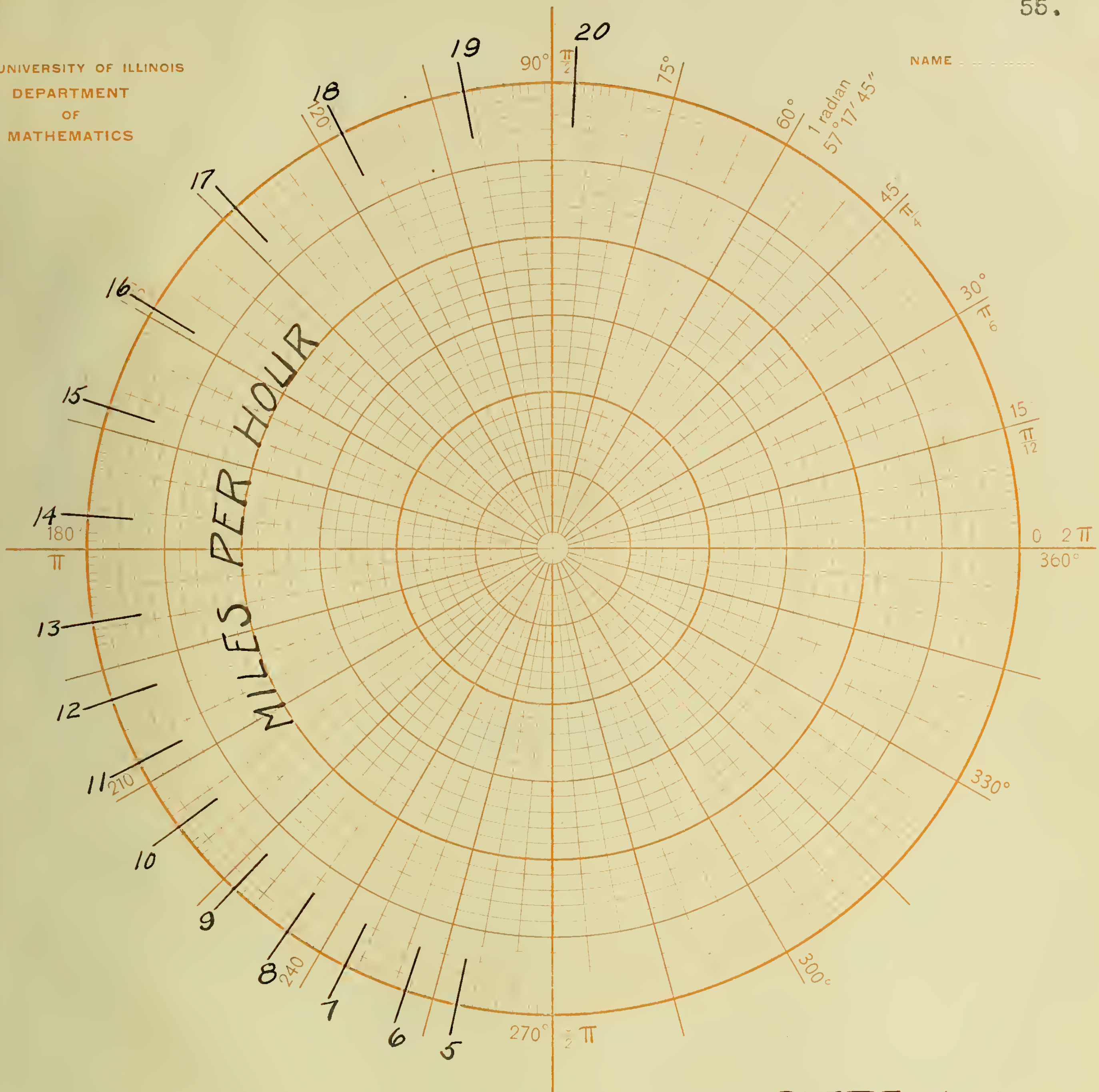


PLATE No 1

GRADUATED DIAL

FOR

BOATOMETER

Initial Tension = 70°

Coefficient = 0.84

May 29, '09.